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**ME 4182
MECHANICAL DESIGN ENGINEERING
NASA/UNIVERSITY ADVANCED DESIGN PROGRAM**

CORE SAMPLE EXTRACTOR

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Abstract

This report addresses the problem of retrieving and storing core samples from a hole drilled on the lunar surface.

The total depth of the hole in question is 50 meters with a maximum diameter of 100 millimeters. The core sample itself has a diameter of 60 millimeters and will be two meters in length. It is therefore necessary to retrieve and store 25 core samples per hole.

The design utilizes a control system that will stop the mechanism at a certain depth, a cam-linkage system that will fracture the core, and a storage system that will save and catalogue the cores to be extracted. The Rod Changer and Storage Design Group will provide the necessary tooling to get into the hole as well as to the core.

The mechanical design for the cam-linkage system as well as the conceptual design of the storage device are described in this report.

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PROBLEM STATEMENT

BACKGROUND

NASA has various needs for holes drilled into the moon's surface. Some of these needs include construction, testing and sample procurement. The auger type drill bit, most likely be used, drills two meters at a time and leaves a center core of rock. This core must then be removed in order for the drill to proceed further. After removal, the core sample must also be stored and catalogued for future testing on earth.

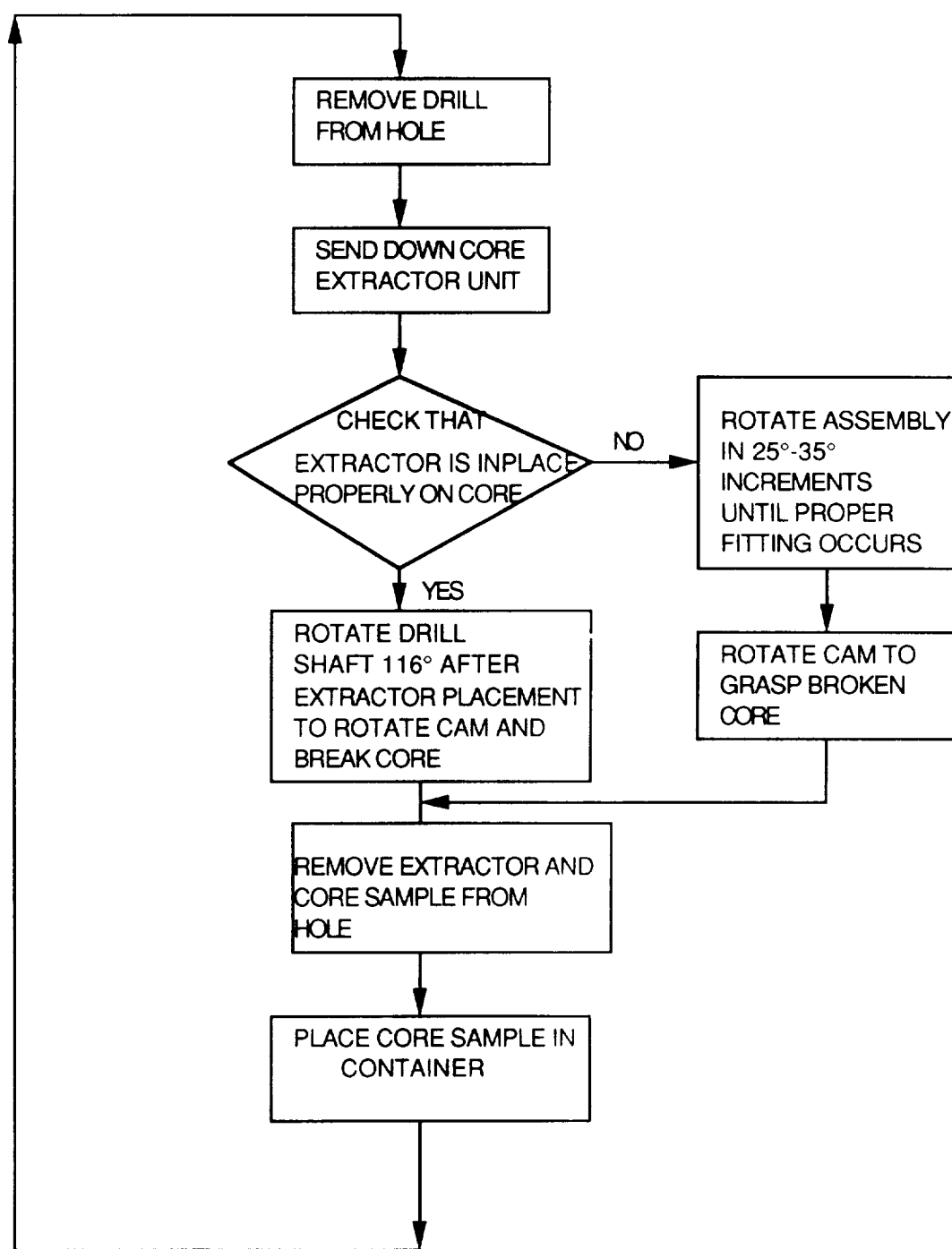
PERFORMANCE

Each core sample of up to two meters in length and diameters of 60 millimeters must be removed from a 100 millimeter diameter hole and stored. Preferably, the cores should be removed in one piece and with very little damage. The depth of the drilled hole can be as much as 50 meters. In the event the core sample should break, it must be kept in its original order when put into the storage container. The storage system should be able to accommodate up to 25 samples per drilled hole and be flexible to allow for a lesser number. The core samples must also be stored in a manner such that their relative original location in the hole can be readily traced.

CONSTRAINTS

The uncertainties involved in determining the core material properties make it necessary to intentionally overdesign the removal device to be prepared for the worst case situation. With the lack of human supervision during the operations, the equipment must be totally automated and self maintaining. Man/machine interaction should not be required during operation since all processes will take place on the moon. The extractor design must also be applicable to varying sample and hole sizes.

Many constraints are placed on the design of the equipment because the removal device will be required to operate in a vacuum. The presence of abrasive sand and rock fragments must be taken into account when designing the mechanism. Large temperature differences must be accounted for as well as the effect of a vacuum on lubricants and working liquids. The reduced gravity considerations also must be included in the design in addition to the high cost of power on the moon. Transportation costs require that the design be made as light and space efficient as possible.



FLOWCHART OF CORE REMOVAL PROCESS

CORE EXTRACTOR DESIGN

Due to the combined length and brittleness of the rock sample, a relatively small bending force is required to fracture the sample if it is applied near the top of the core. The proposed extractor design uses a rotating cam to push apart two blocks near the top of the sample. One of these blocks has the same contour as that of the wall of the hole and fits against it. The other block fits against the core sample and has the same contour as that of the core sample. The cam is then positioned between these blocks. After the block mechanism has been inserted between the wall and the core, the cam is rotated 90°, pushing the blocks apart. The wedge and the block are tied together using slides as shown in Figure 2 to prevent any lateral movement. The inner block, or wedge as it is referred to in the drawings, is angled on the surface next to the core. The purpose of the 2° angle taper is to better distribute the force when the core deflects and moves away from the block at the top. It also allows the tip of the wedge assembly to be narrower, allowing easier placement into the space between the core and wall. In order to prevent the entire assembly from rotating, the wedge and cam assembly is slightly wider (due the angle of taper) at the base end so that upon insertion it will wedge slightly between the core and wall. This should be more than adequate to hold the assembly in place.

As the cam/wedge assembly pushes the core and breaks it, an opposing fork, which is also contoured to the core, slides inward and the sample is held between the wedge and the fork. The inner surface (the surface the cam rotates against) of the wedge has a slight notch or groove running the entire length of the cam. This holds the lobe of the cam after it has been rotated fully and locks the hold on the core sample so it can be transported to the surface.

A simple frame is used to hold the drill rod shaft and cam end shaft in place. The bearings needed for smooth rotation should either be sealed from the vacuum or a solid lubricant such as

graphite used. The double frame which is tied together will resist the tendency of the cam to travel as it is being rotated and keep the cam in the proper position.

To this frame is then added the support frame for the fork and wedge. The fork support contains one slot for the fork slide to move in, allowing the fork to move in and out. This support is then braced to the support for the wedge. The wedge is attached to the support and does not slide (the entire extractor will move over when the cam is rotated). The support is tied to the main shaft frames on each side and a bar runs between them where the wedge is attached.

The drill shaft rotation must be transformed and translated to create the rotation motion of the cam and the sliding motion of the fork. A 4-bar linkage mechanism is used to rotate the cam shaft as is shown in the figure. The explanation of the design of this linkage is found in the following section.

The sliding motion of the fork is produced using a slider-linkage mechanism. This is a simple mechanism that is driven by a small shaft of approximately 1.0 cm diameter that is connected directly to the drill shaft. The linkage is designed so that the fork is pushed completely out when the wedge blocks are together. When the drill shaft rotates and turns the cam, pushing the blocks apart, the fork is pulled inward to its minimum position, grasping the core sample.

The operation described above is for the case of an intact core. If the core should break during removal of the drill assembly, the core sample must still be removed. The opposing fork design of the extractor mechanism allows the retrieval of broken samples. The distance the mechanism has traveled down the hole is known by the number of drill rods used. The same number of two meter drill rods will be required to lower the extractor to the bottom as was used for the drill. If the position of the last rod assembled does not correspond to its position before the drill was raised, then the

extractor is not inserted properly around the core. In the case of the downward motion of the extractor and shaft being impeded before it reaches its proper position, the entire assembly can be lifted up a small amount and rotated approximately 20° then lowered again. This process is repeated until the fork and wedge are aligned properly so that they will slide down around the core which will be laying against the side of the shaft wall. The cam can then be rotated and the broken sample grasped.

In order to prevent the extractor from getting caught against the walls of the shaft on the way down to the sample, the fork and wedge will be sent down in the same position as they would be with a grasped core sample. This will bring them closer together and reduce the possibility of them catching wall irregularities. The entire assembly could also be rotated slowly on the way down which would help prevent the extractor from lodging against the wall. If the extractor should become wedged on the way down, the same procedure that aligns it with a broken core could then be used to free the device.



CORE SAMPLE EXTRACTOR

RIGHT VIEW

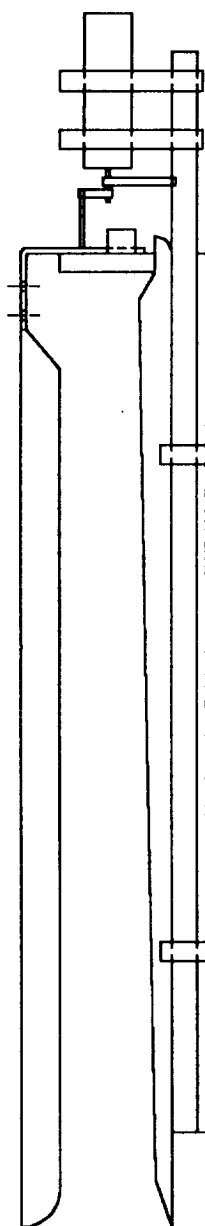
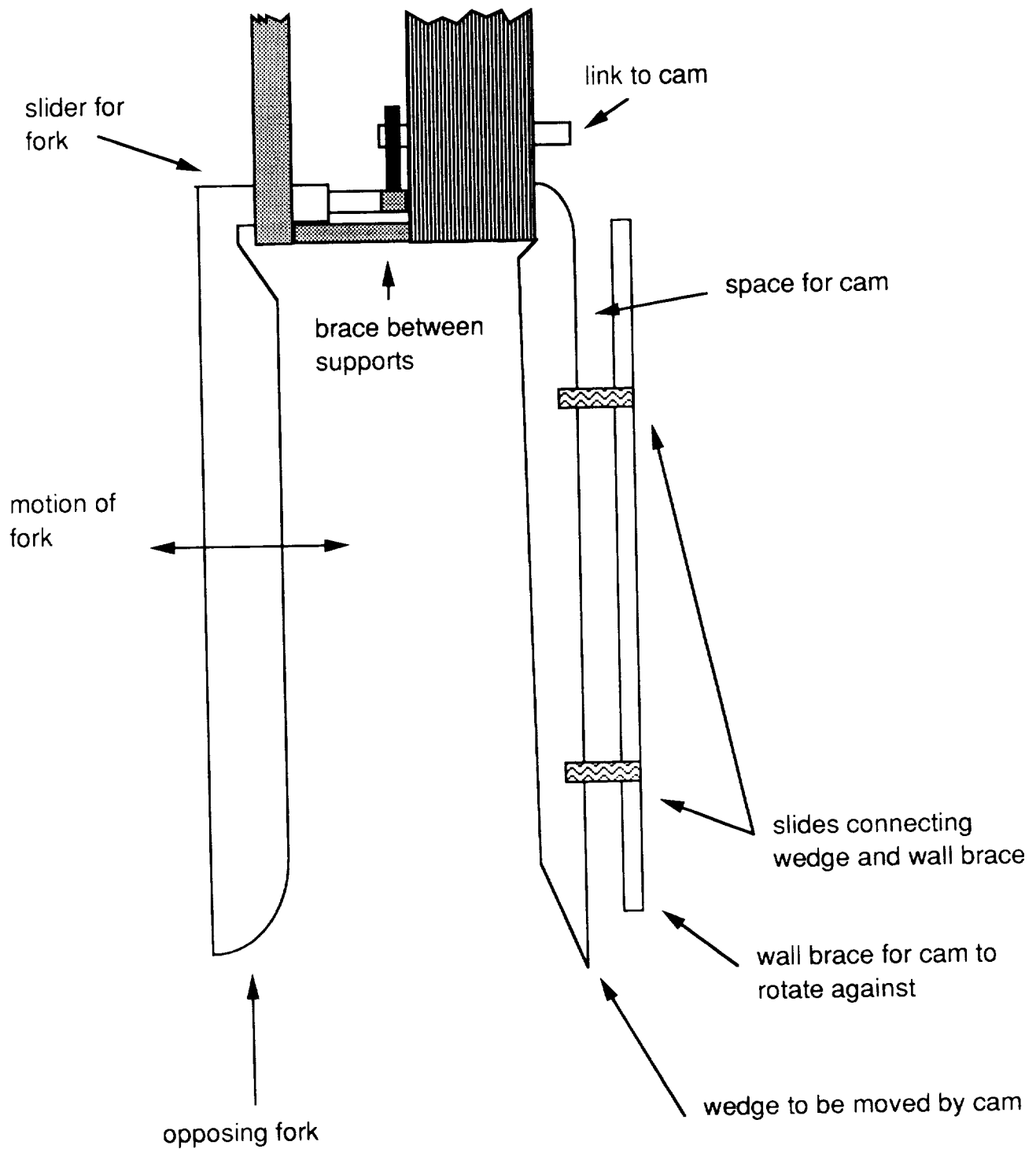


Figure 2



As cam turns, the fork and the wedge move inward together, grasping the core which is broken by the inward movement of the wedge

Figure 3

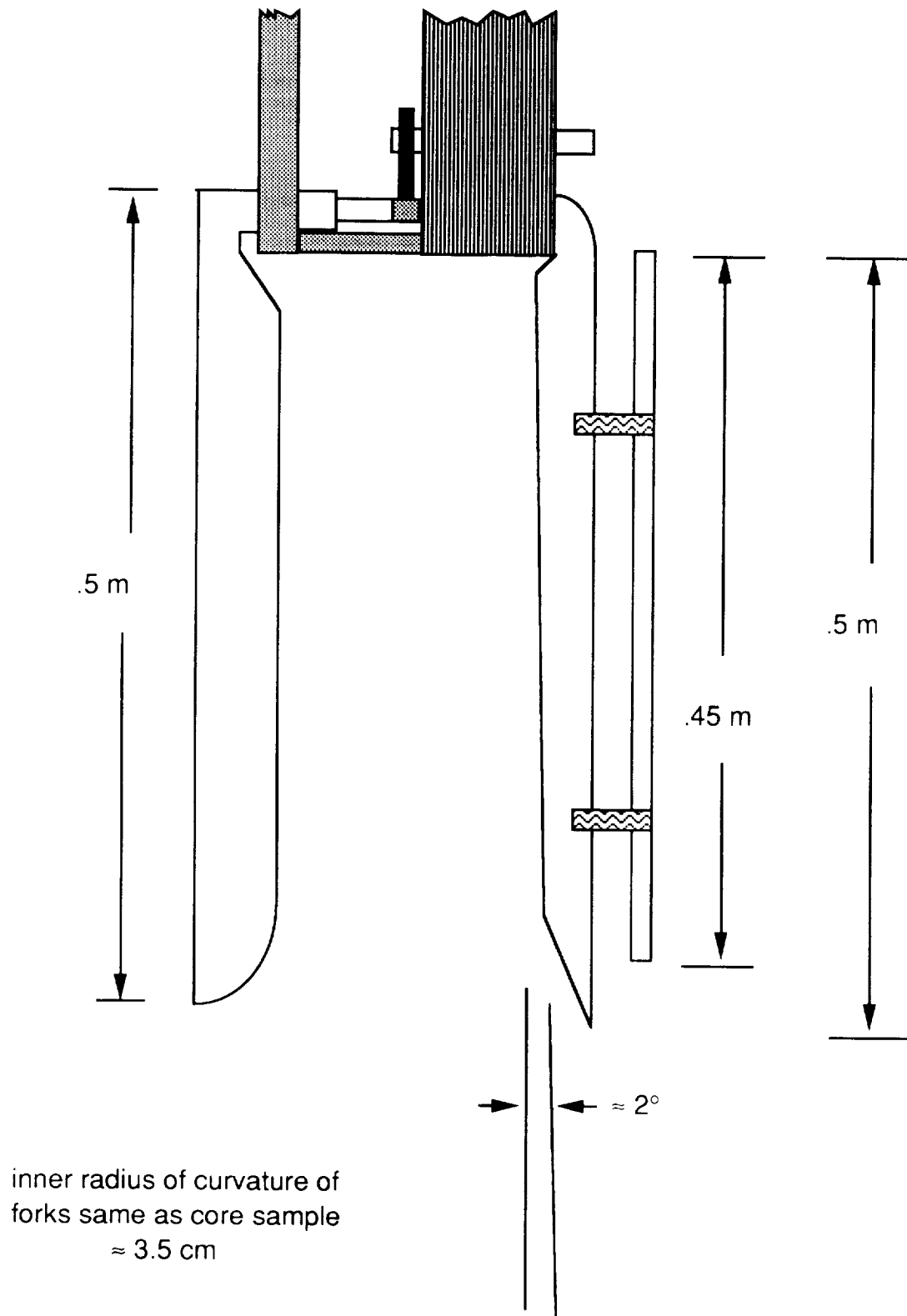
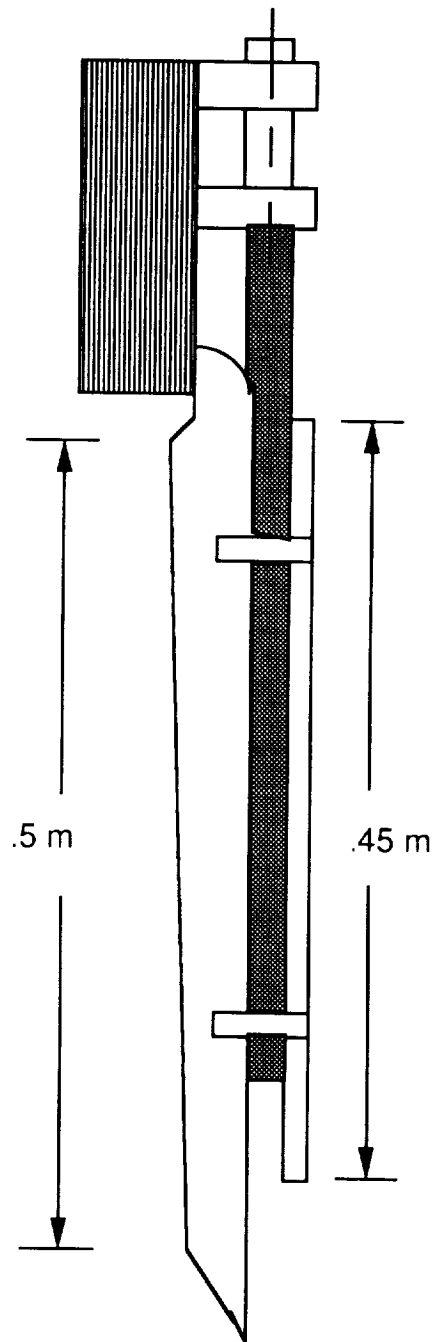
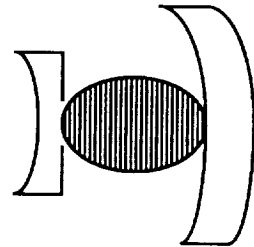


Figure 4

CAM AND WEDGE ASSEMBLY



top view of cam and
wedge in separated
condition



wedge and wall brace contoured to fit
core and wall respectively

Figure 5

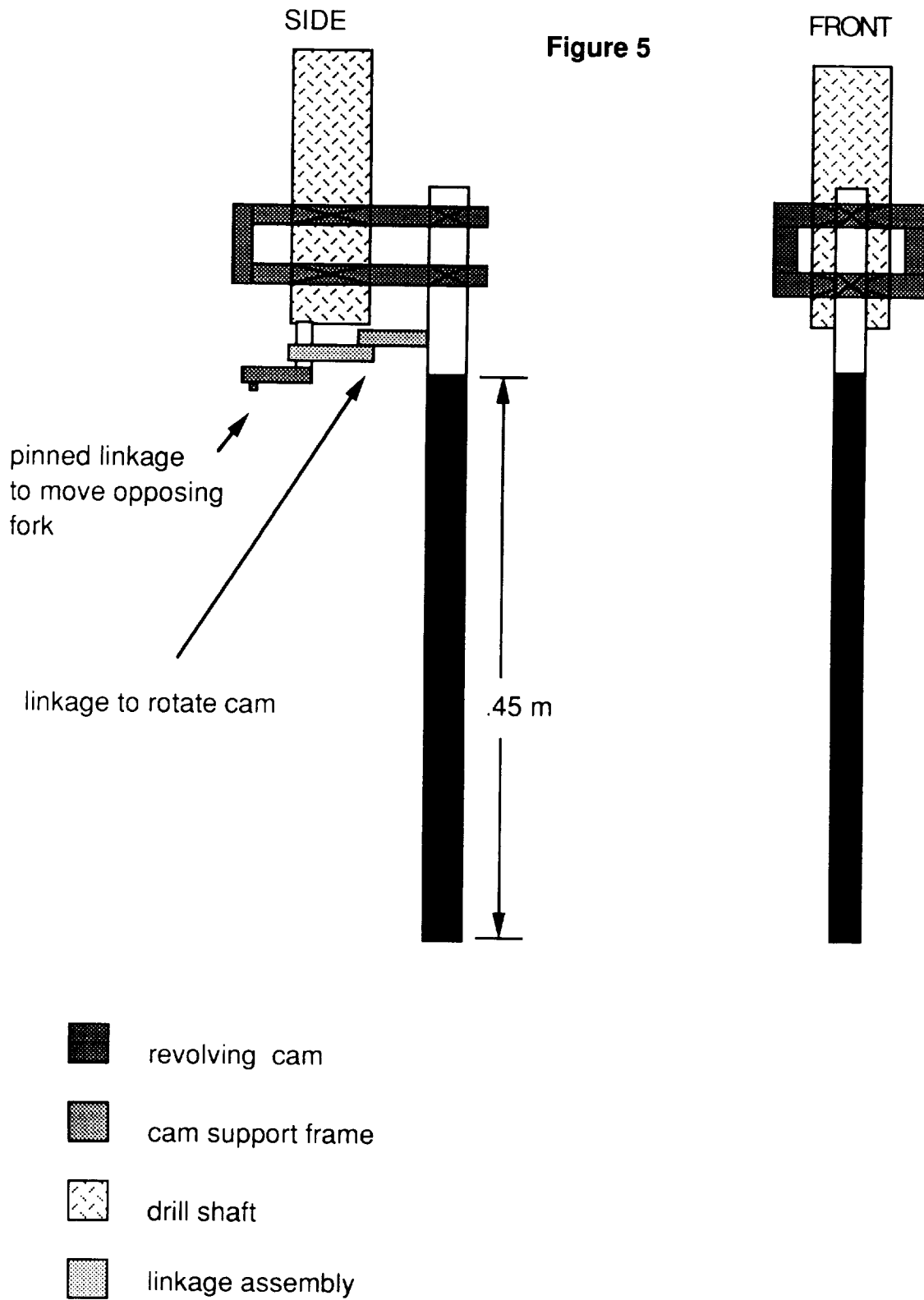


Figure 6

Linkage layout and attachment to end of main shaft

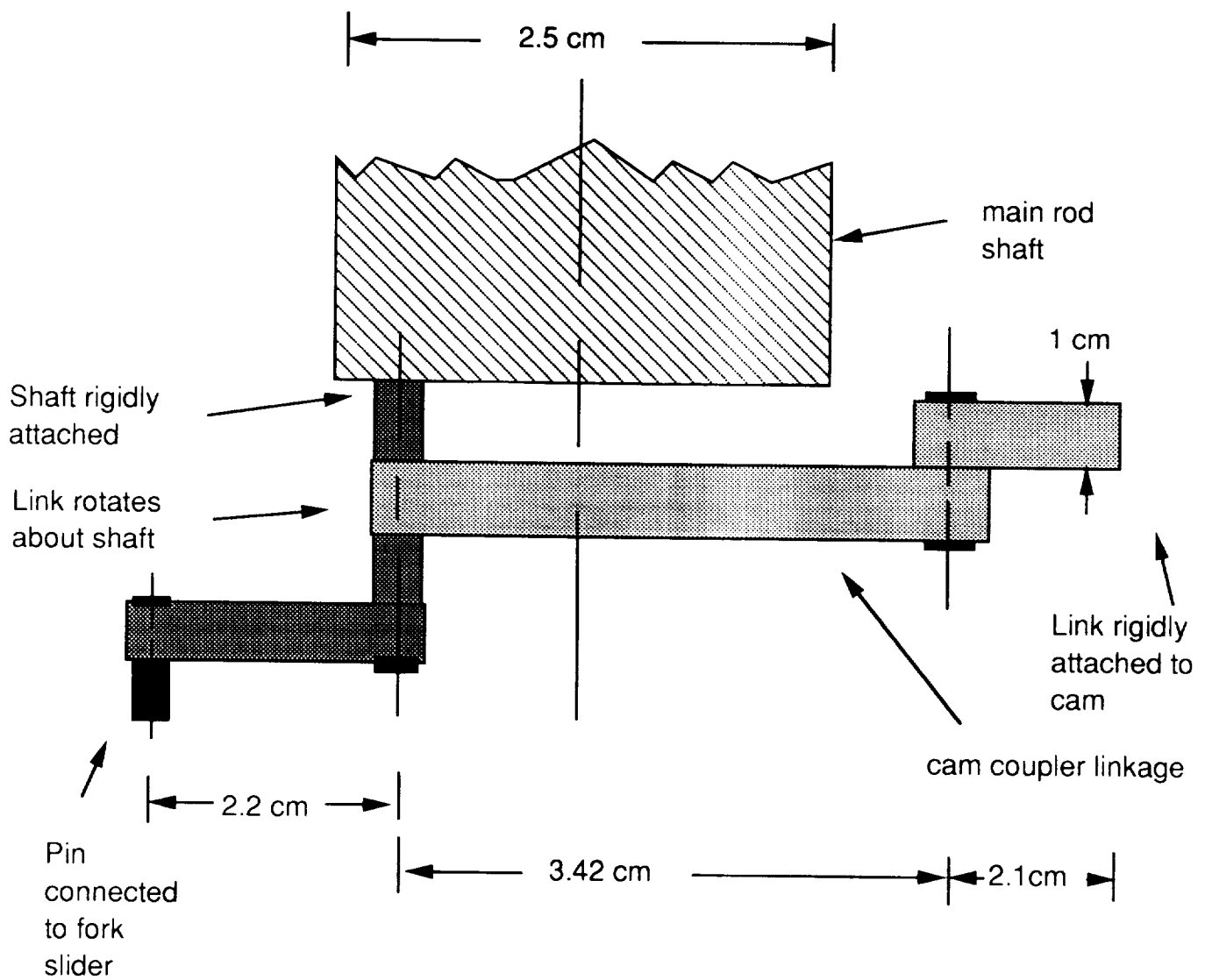
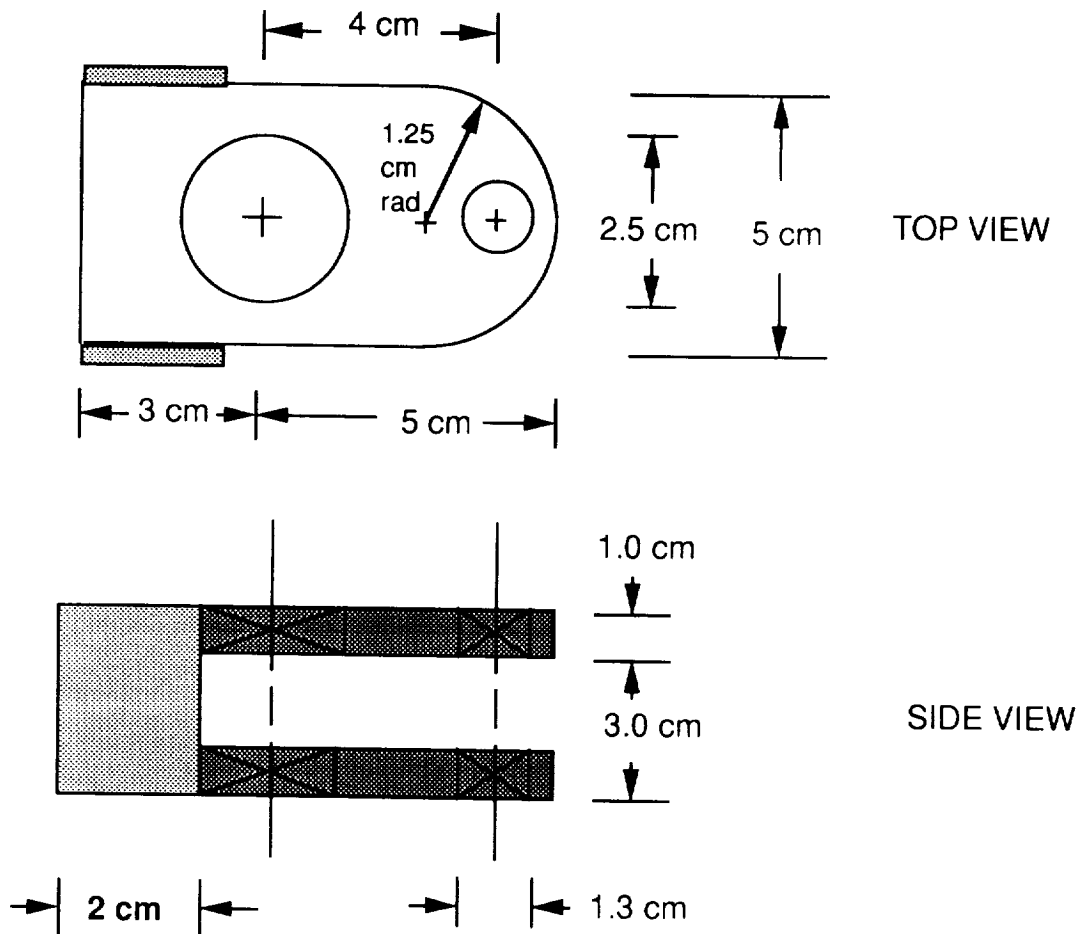


Figure 7

Frame to hold drill shaft and cam shaft. This is considered the frame link of the linkage system driving the cam.





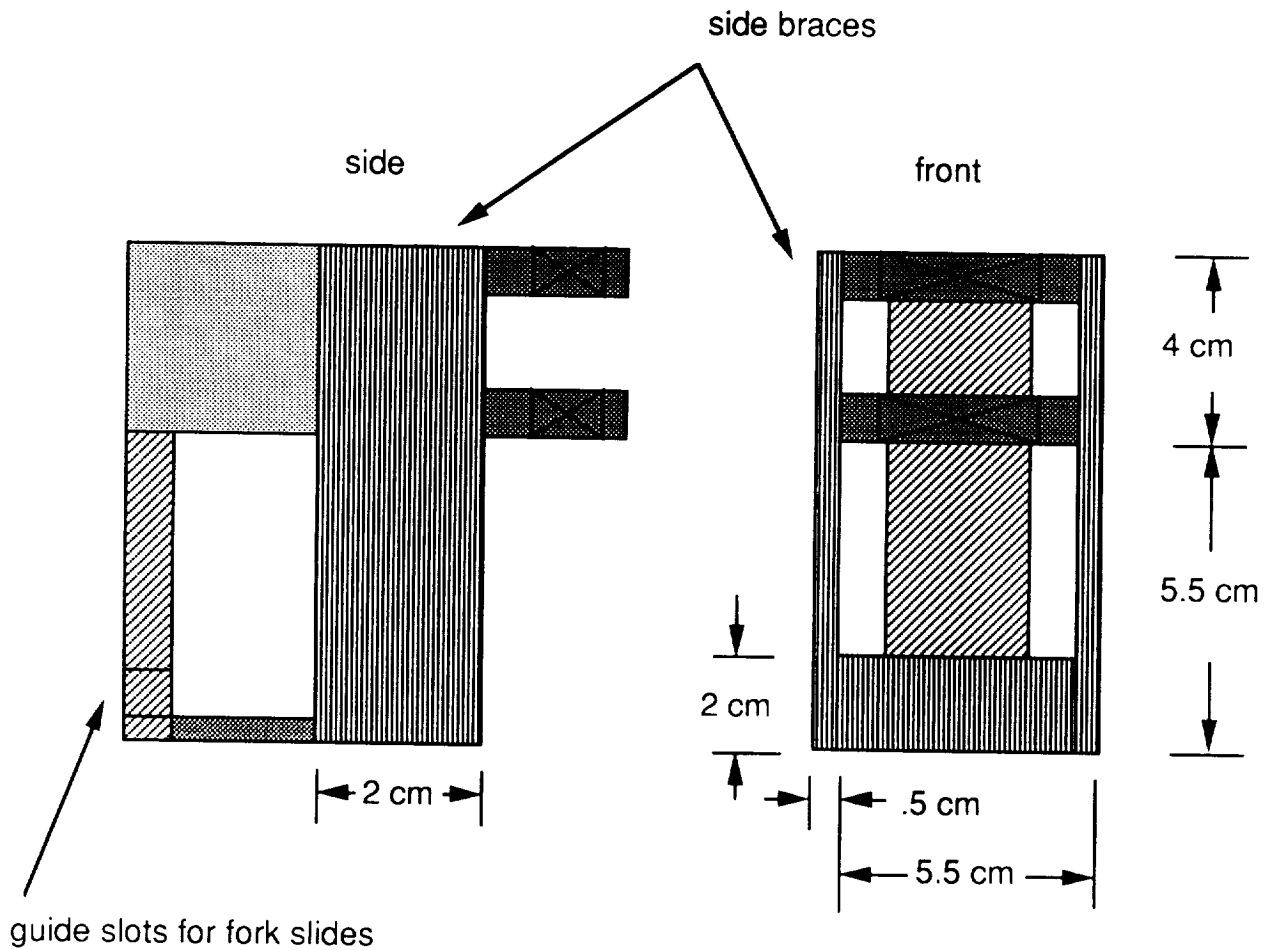
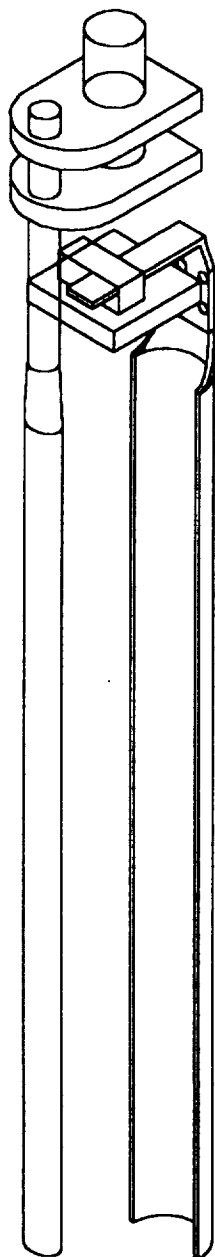
-  shaft support structure
-  core fork support and guide
-  wedge fork support
-  shaft support structure ties

Figure 8

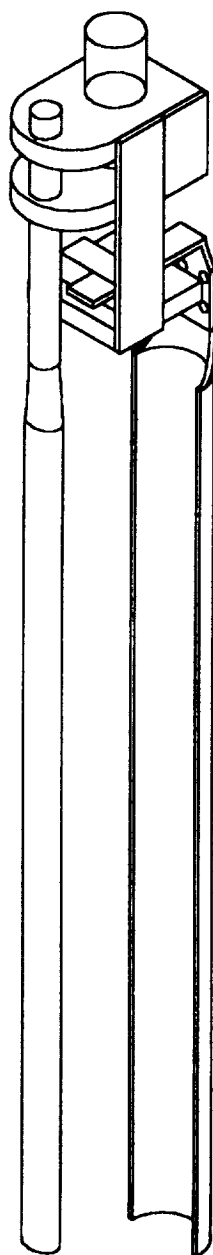
COMPLETE SUPPORT STRUCTURE FOR SHAFTS AND FORK/WEDGE ASSEMBLIES

CORE SAMPLE EXTRACTOR





SAMPLE EXTRACTOR WITH SUPPORT STRUCTURE



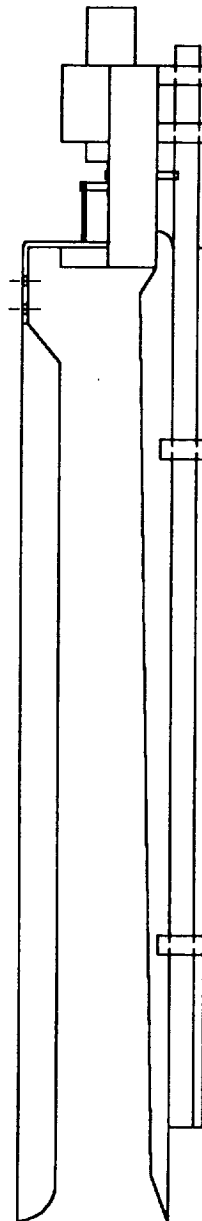


CORE SAMPLE EXTRACTOR FRONT VIEW





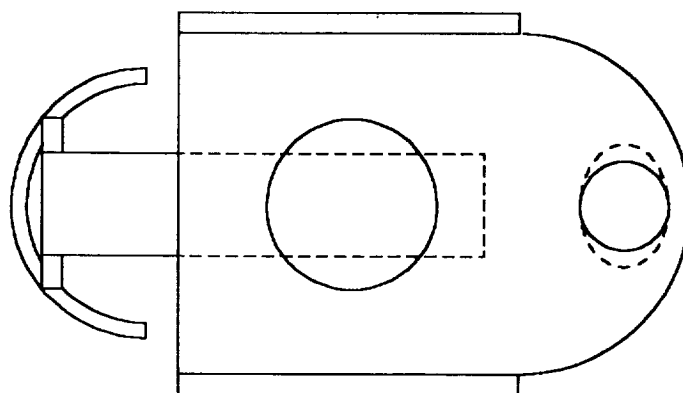
SIDE VIEW WITH SUPPORT STRUCTURE





CORE SAMPLE EXTRACTOR

TOP VIEW



Cam Design

In order to design the cam, the amount of deflection needed to break the sample was calculated. It was assumed that two meter rod acted as a cantilever beam. This enabled the use of the differential deflection formula $v'' = M(x)/EI$ (v'' is the second derivative of deflection, $M(X)$ is the moment as a function of x , and I is the moment of inertia). It was assumed that any force acted on by the cam was distributed evenly on the core sample. With this assumption, the differential equation was integrated twice in order to determine the necessary amount of deflection.

An elliptical arc cam was chosen for the Core Sample Extractor. From the deflection calculations, the cam was designed to displace a distance of 6 millimeters, and the tolerance of the outside wall to the core sample was 12 millimeters. With this information, a computer program was written in order to calculate the torque exerted on the cam.

In order to do this, some assumptions were made. Due to the distance between the core sample and the wall, the cam would only be able to rotate eighty degrees. A linear displacement profile was assumed for the cam. This would allow easy calculations with relative accuracy. The linear profile allowed for minimal acceleration during the cam rotation, which was caused by the change in mechanical advantage in the linkage mechanism.

The maximum torque calculated was equal to 3.6 inlbs. Due to lack of lubrication and debris getting between the wall and cam, a steel with high hardness properties should be selected. Due to the fact that the cam is very long as compared to its diameter, a high strength material is required. Possible candidates are: AISI 1045, AISI 4142, or AISI 3130.

LINKAGE DESIGN

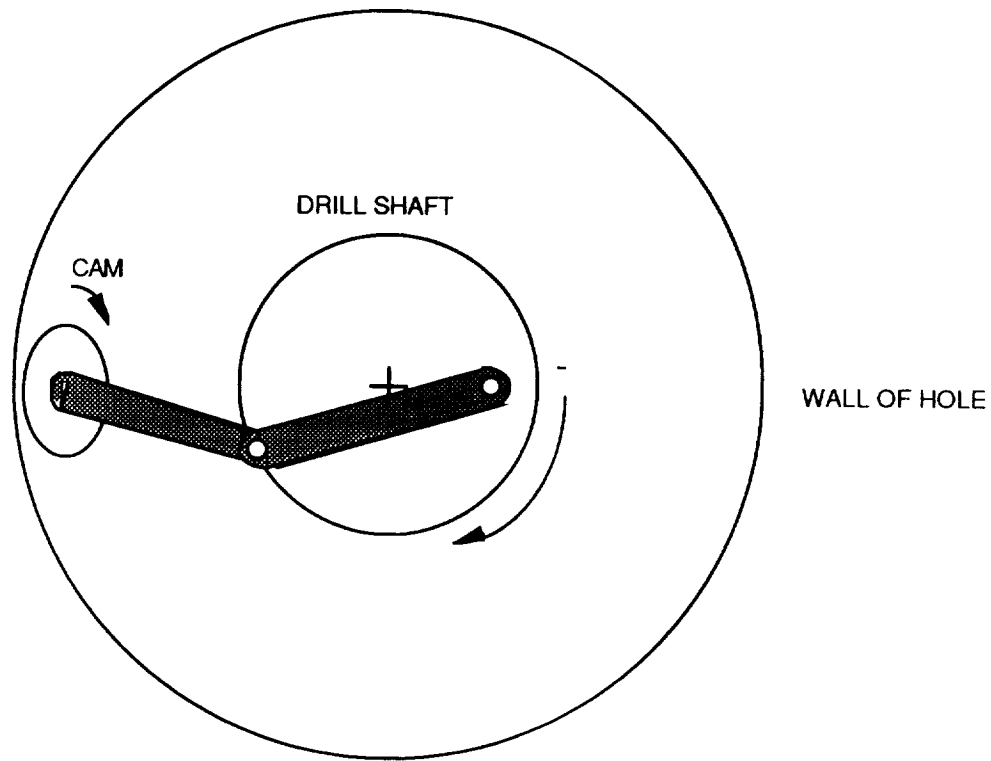
In order to transmit the torque from the drill shaft to the cam, a four bar linkage mechanism was adopted. A major advantage of such a system is that it would be able to produce a torque increase from the drill shaft to the cam.

The following factors were considered during the design of the four bar linkage: the space limitations, the output link having to rotate eighty degrees, a large mechanical advantage needed at the start of the cam rotation, and a mechanical advantage greater than one needed throughout the linkage's motion. Due to the size of the hole the linkage had to be small. For the cam to rotate eighty degrees the follower (output) link had to rotate one hundred sixteen degrees. To attain a eighty degree rotation, without hitting the wall, the follower link could be no longer than 2.1 cm. A major objective of the linkage design was to produce a high mechanical advantage. Mechanical advantage is defined as the ratio of the output torque to the input torque this is equal to $(RCD \cdot \sin(\gamma)) / (RAB \cdot \sin(\beta))$. Where RCD is the length of the follower, γ is the angle between the coupler and the follower, RAB is the length of the input link, and β is the angle between the input link and the coupler. From this definition it is easily seen that to increase the mechanical advantage the follower should be larger than the input link; also if β is 0 or 180 degrees the mechanical advantage gets very large. In the design of the cam it was determined that the largest torque was needed in the beginning rotation of the cam; this is to overcome the static friction force on the cam. To reduce the torque needed from the drill, during the start of rotation, a large mechanical advantage was designed into the beginning rotation of the four bar linkage. To achieve this higher mechanical advantage the linkage was designed so that β would start off very small. To achieve the largest mechanical advantage the maximum follower length (2.1 cm) would be used. To attain a follower rotation of eighty degrees the minimum input link length

would be 1.5 cm. To maximize mechanical advantage, with angles, and to assure proper direction of rotation; a coupler length of 3.42 cm was determined. These dimensions produced a high mechanical advantage in the early rotation of the linkage and resulted in a mechanical advantage of no less than 1.25 throughout the rotation of the linkage.

The material needed for the linkages must be resistant to the effect of large temperature changes. It must also be able to withstand the stresses in the material. Because of this, we propose a cold worked tool steel be selected, such as tool steel A2 or D2.

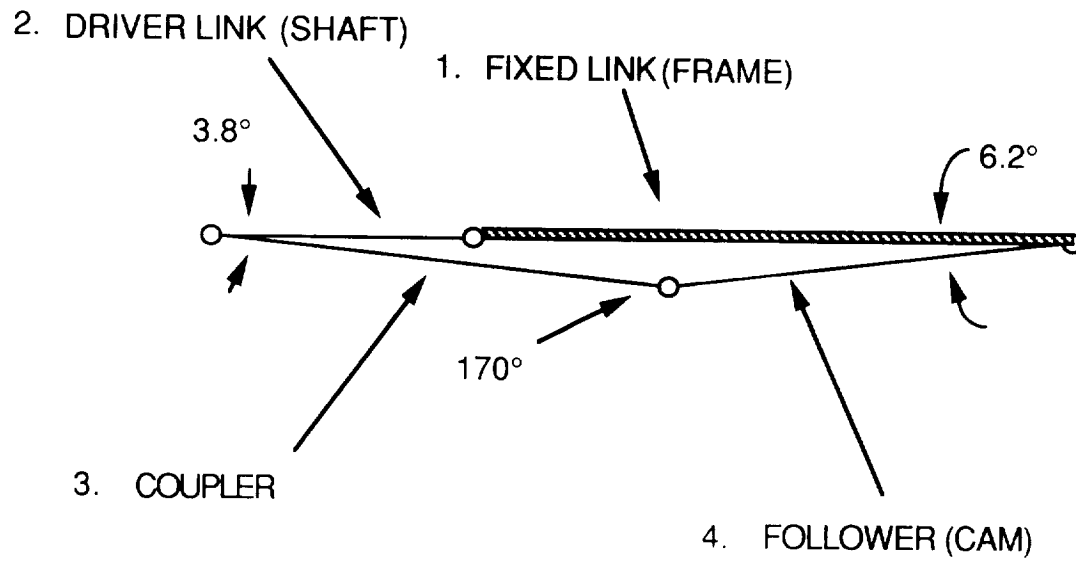
TOP VIEW OF LINKAGE TO ROTATE CAM



The drill shaft is above the linkage assembly and is the driving arm of this 4-bar linkage. The output link is solidly connected to the cam and can not rotate with reference to the cam. The cam shape is shown here for reference only. The driven arm will be connected to a shaft which will then be directly connected to the cam below the linkage assembly.

Figure 15

INITIAL POSITION (BEFORE TURNING CAM)



LENGTHS:

- 1. 4 cm
- 2. 1.5 cm
- 3. 3.42 cm
- 4. 2.1 cm

FINAL POSITION (CAM TURNED $\approx 90^\circ$)

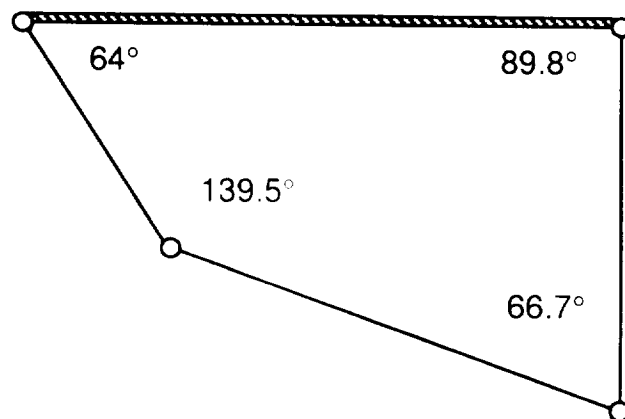
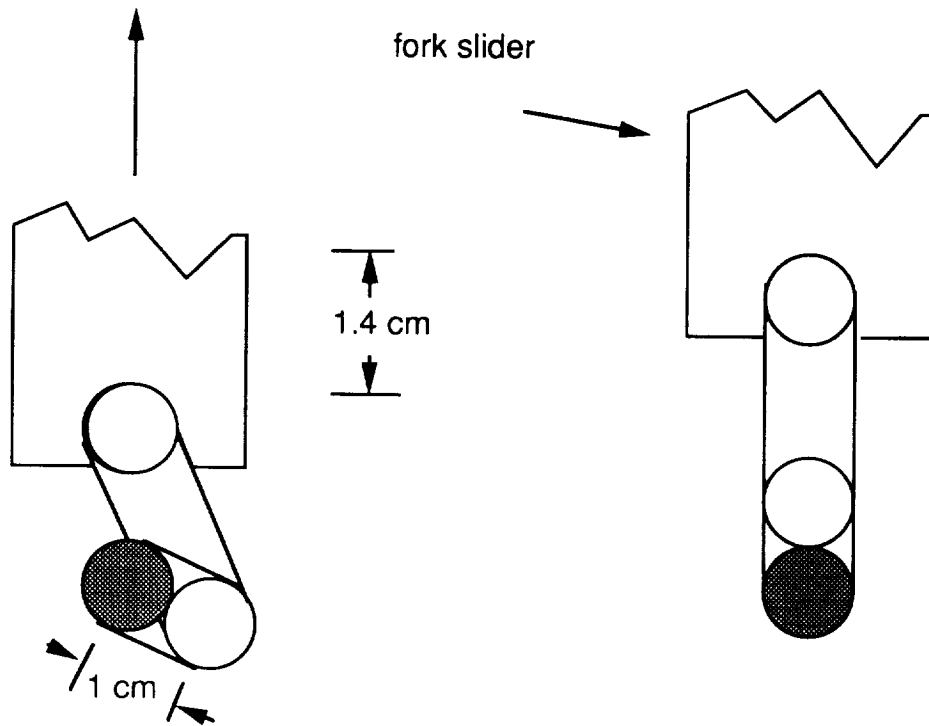


Figure 16



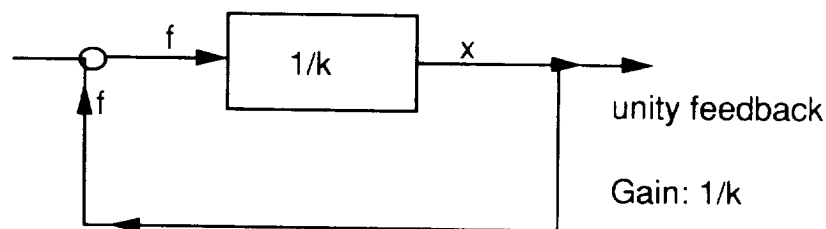
The main shaft will rotate 116° to make the cam rotate 90° .
The linkage is designed to move the block 1.4 cm with a shaft rotation of 116° .

LINKAGE FOR FOR SLIDE MOVEMENT

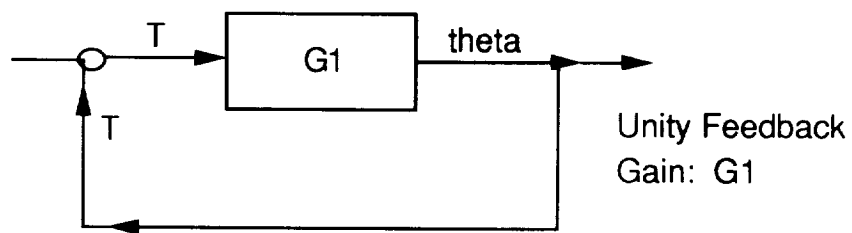
Control System Design

With the small tolerances between the Core Sample and the Wall of the hole, there is a need for some mechanism to control how the extractor should go into the hole and when it should stop. In a similar manner, there should also be an additional device that will control the motor that rotates the cam-linkage system in breaking the sample. The following ideas for such a system have been proposed.

When the core extractor device firsts hits the core sample, Skitter will exert a force downward. Unless some sensing mechanism is incorporated on the bottom of the core extractor, the Skitter will continually increase this force. A simple "soft" spring on the bottom of the extractor could measure the distance between the core extrator and the top of the core sample. Knowing the spring constant and the tolerabe distance, the force could be easily controlled using $F=kx$. A block diagram would look like the following:

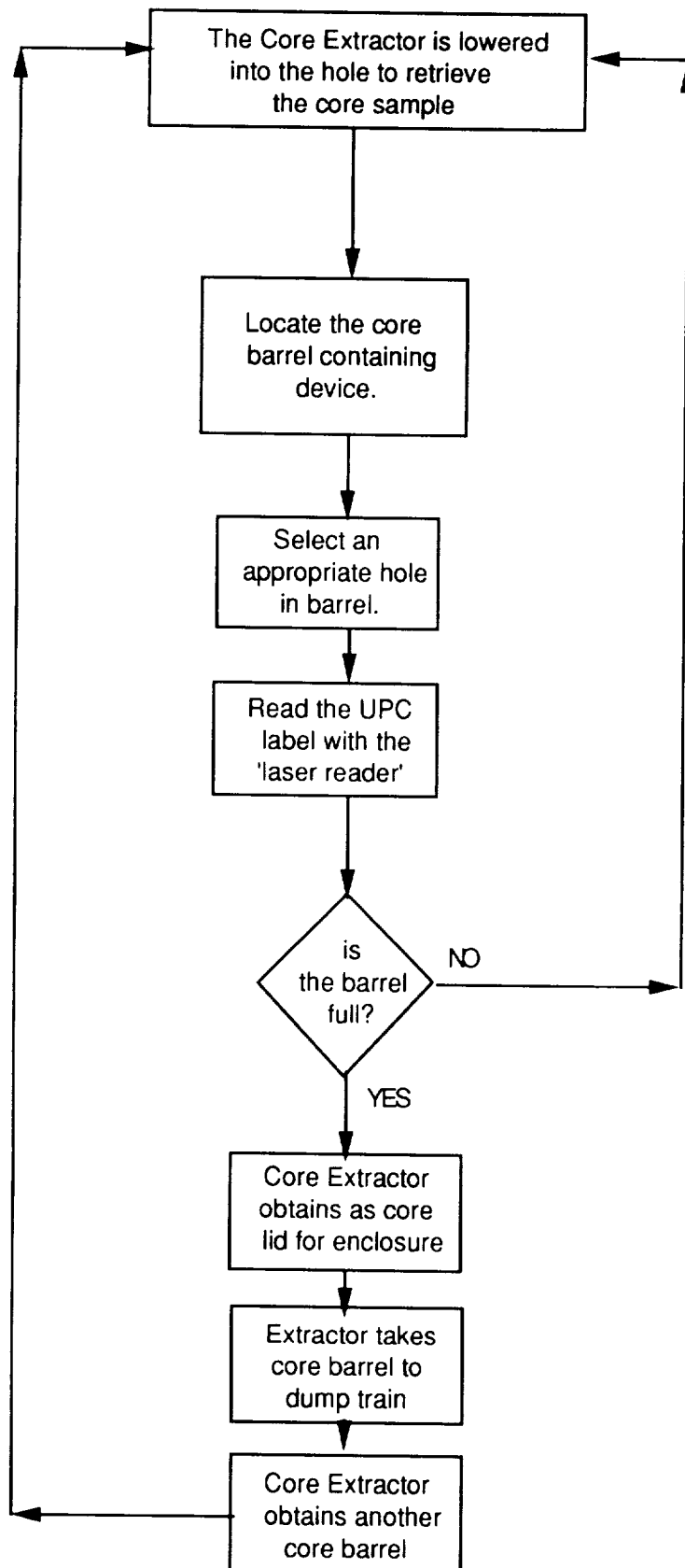


It is also necessary to have a control system on the motor that rotates the cam. Without this device, either one of two things would happen. The motor would not be able to start the cam for the needed rotation, or the cam would not stop at the needed angle of rotation. In addition, this device could act as an interface to the electrical input to the mechanical output. Since the extractor system is using linkages, the rod changer must rotate to an angle of 116 degrees. This will ensure that the control device turns the necessary eighty degrees of rotation. Basically, the control mechanism necessary for this operation will ensure that the rod is rotated exactly 116 degrees. A block diagram is as follows:



Although simplified as it is, our group feels that the control mechanism outlined will be able to perform as needed. It is important to realize that the major purpose for such a control mechanism is the interfacing between the electrical input and the mechanical output.

FLOWCHART OF CORE SAMPLE CONTAINMENT AND CATALOG SYSTEM



DESIGN AND DEVELOPMENT

The core sample container apparatus is a conceptual idea and not a finalized one. The main goal of the container is to store and categorize the extracted core samples. Assistance will definitely need to be provided by the rod changer group. In the following discussion, the basic steps will be provided for the total process to begin and end.

After the core sample has been broken and retrieved from the hold, the mechanism will be taken to a core barrel container device located at a close proximity to the hole. This core barrel is simply a circular container, 2000 mm in length, with a diameter of 370 mm which contains 18 holes, each having a 65 mm diameter. The core barrel also has a 7 mm screw thread for a fastening lid which will enclose the core barrel. It would be very advantageous if the rod changer group could design a moveable arm with several degrees of freedom. When the core extractor has reached a desired hole in the core barrel, it will proceed to drop that sample in that desired hole. Each hole has already been pre-labeled with a UPC bar graph. The use of a laser much like those used in grocery store applications, would be able to read this bar graph and put it into memory when the desired time arrives.

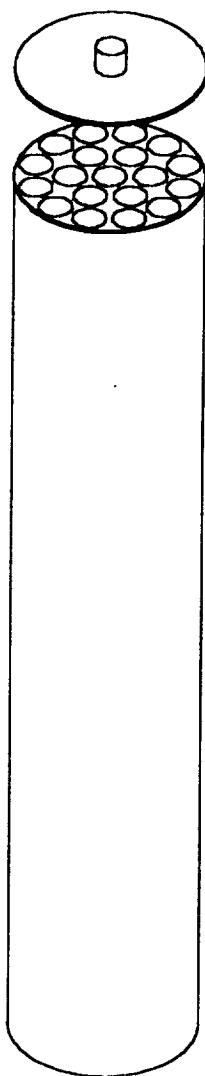
Upon completion of filling the eighteen holes, the core extractor device will move to another location to grasp a fastening lid for the core barrel. A simple 180° turn will guarantee a totally enclosed container. Because the size of the core barrel is greater than the maximum opening of the core extractor, it is necessary to grasp the device by means of a lid holder which is situated in the center of the lid. This lid holder will have a nominal value of 60 mm in diameter, and 50 mm in length, and thus appropriately be situated for grasping and turning the core barrel lid.

Once the core barrel has been contained, it will be picked up by the core extractor and taken to a dump truck. This dump truck, which is 2134 mm in length, 2590 mm in width, and 2743 mm in height, has been especially equipped with inclined ramps. These ramps, angled at 10-15 degrees above the horizontal, will operate on

the same premise as soda cans do in a soda machine. When the core extractor locates the dump truck, the core extractor and container barrel will be rotated 90° to a horizontal position. This will guarantee uniformity of the core barrel and alignment with the ramps. The first core barrel will be dropped at the top of the ramp and will uniformly roll to the next incline ramp. This process will proceed until the core barrel has reached the bottom of the dump truck. It would be most advantageous to implement an escape hatch at the bottom of the dump truck to allow easy unloading of the core barrels. This principle would work similar to that of cargo trains in the railroad industry. These ramps are designed such that they are easily placed into the dump truck. This total process can now be repeated by locating an empty core barrel and starting over again.

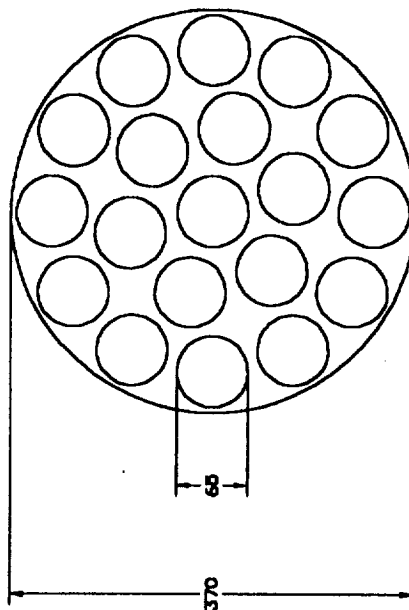
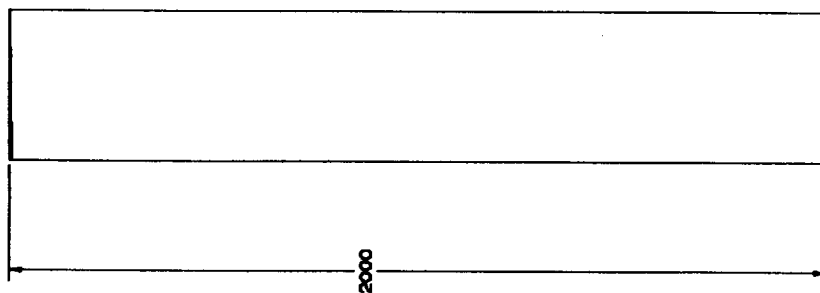
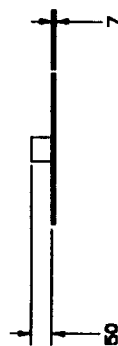


CORE SAMPLE CONTAINER

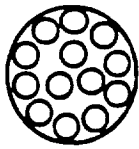




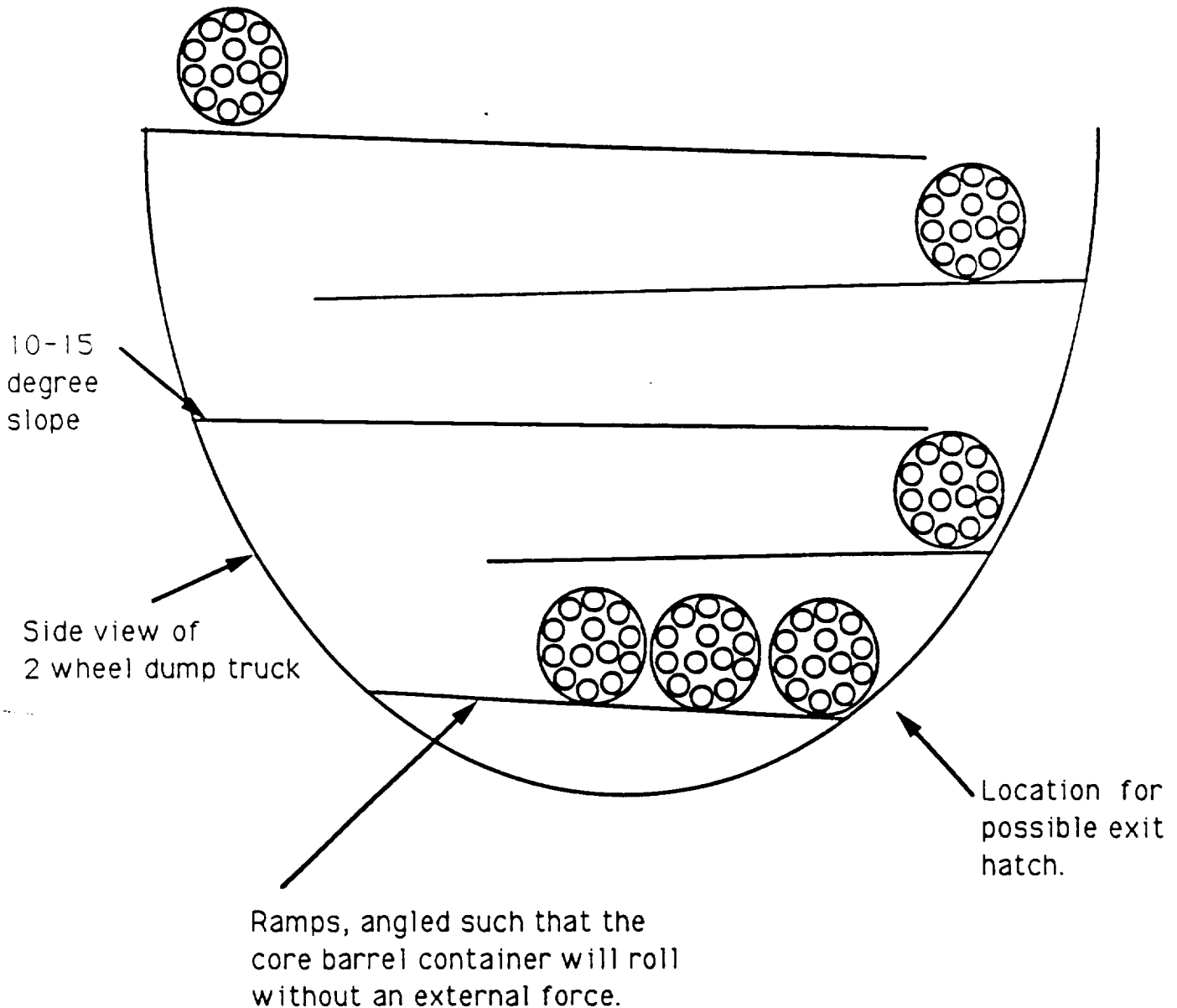
CORE SAMPLE CONTAINER (IN MILLIMETERS)



Core Sample Container Design



A typical core barrel container.
This container will hold 3-6 meter
samples per hole



The ramps will be made such that they will be easily retrofitted into the dump train.

Report Conclusion

It is the belief of our design group that the proposed design of the core sample extractor and core sample container will satisfactorily perform as specified. It should be noted that the space limitations imposed by the deep and narrow drilled hole, the lunar environment, and the lack of information concerning the rock properties added to the complexity of the project.

Many ideas were presented in the design of the core sample extractor. The proposed cam driven core extractor mechanism was selected after evaluating the advantages of such a system. These included the mechanical advantage in torque produced by the linkage assembly and the elimination of an additional mechanism to remove a core sample that was already broken. A major concern, and one we feel has been properly addressed and solved, is the design of a linkage system that would operate in the limited space provided. Provided that the recommendations are noted and incorporated into the final design, we feel that the mechanism described within this report will effectively remove a core sample from a drilled hole on the moon.

The design of the Core Sample Container is conceptual and needs some refinement. The container system presented in this paper has the advantages of simplicity, systematic cataloging of core samples, and the interfacing with the Two-Wheeled Dump Train. Although some details and in-depth calculations are not included in this report, our group is in agreement concerning the feasibility of such a containing device.

RECOMMENDATIONS

CORE EXTRACTOR

1. Design testing should be completed using Ilmenite. All current calculations have been made using Granite as a worst case scenario.
2. Testing to locate the point where maximum mechanical advantage is needed should be conducted. Currently the linkage is designed to provide this advantage at the start of the stroke.
3. The angle of the extractor wedge should be evaluated to optimize the core breakage point and force distribution along the sample.
4. The relationship of the length of the wedge assembly to the point of core breakage should be predicted.
5. Additional work concerning the optimization of the cam loading design should take place.
6. An investigation of methods to seal the cam from outside dust and contamination should be conducted.
7. The software for the control system should be defined and developed.
8. The placement of the sample storage apparatus and the core extractor on skitter should be optimized.
9. An interface between the arm and the core extractor should be designed.

RECOMMENDATIONS

CORE SAMPLE CONTAINER

1. The rod changer group should spend time on a rotating arm(robotic) to handle the operations that we are devising. (Have several degrees of freedom).
2. More efficient way of labeling the samples, other than what we have proposed. Lasers might be expensive and unworthy.
3. Have separate attachment, other than core extractor, to attach to the core barrel lid. This would eliminate the need of a holding bar.
4. Change the dimensions of the dump truck if found necessary.
5. At the entry to the dump truck, possibly design a rail system in which the core barrel would enter uniformly on the two rails on each side of the inclined ramp and thus roll evenly down the ramp.
6. Have the center piece of the core barrel lid be notched, and also the core extractor grooved, so that when the handle "locks" onto the center piece, to ease lifting of the barrel.
7. Load the rod changer arm so that it can withstand the necessary amount of weight when the barrel is lifted.
8. Have two latches at the bottom of the dump truck activate to open the hatch and dump the samples when the train is at the desired location.
9. Design a unique method to stack the empty core barrels so that they are easily accessible.

10. Have grooves in the inclined ramps to adjust the barrel if it becomes misaligned.
11. Have a control system to monitor the entire operation.
12. Design a "core sample center" where the barrels can be released from the dump truck and stored. This center could consist of tracks similar to those in a car wash which would contain the mechanism to open the dump truck hatch.

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Appendix

8.1

Four Bar Linkage Computer Program

```

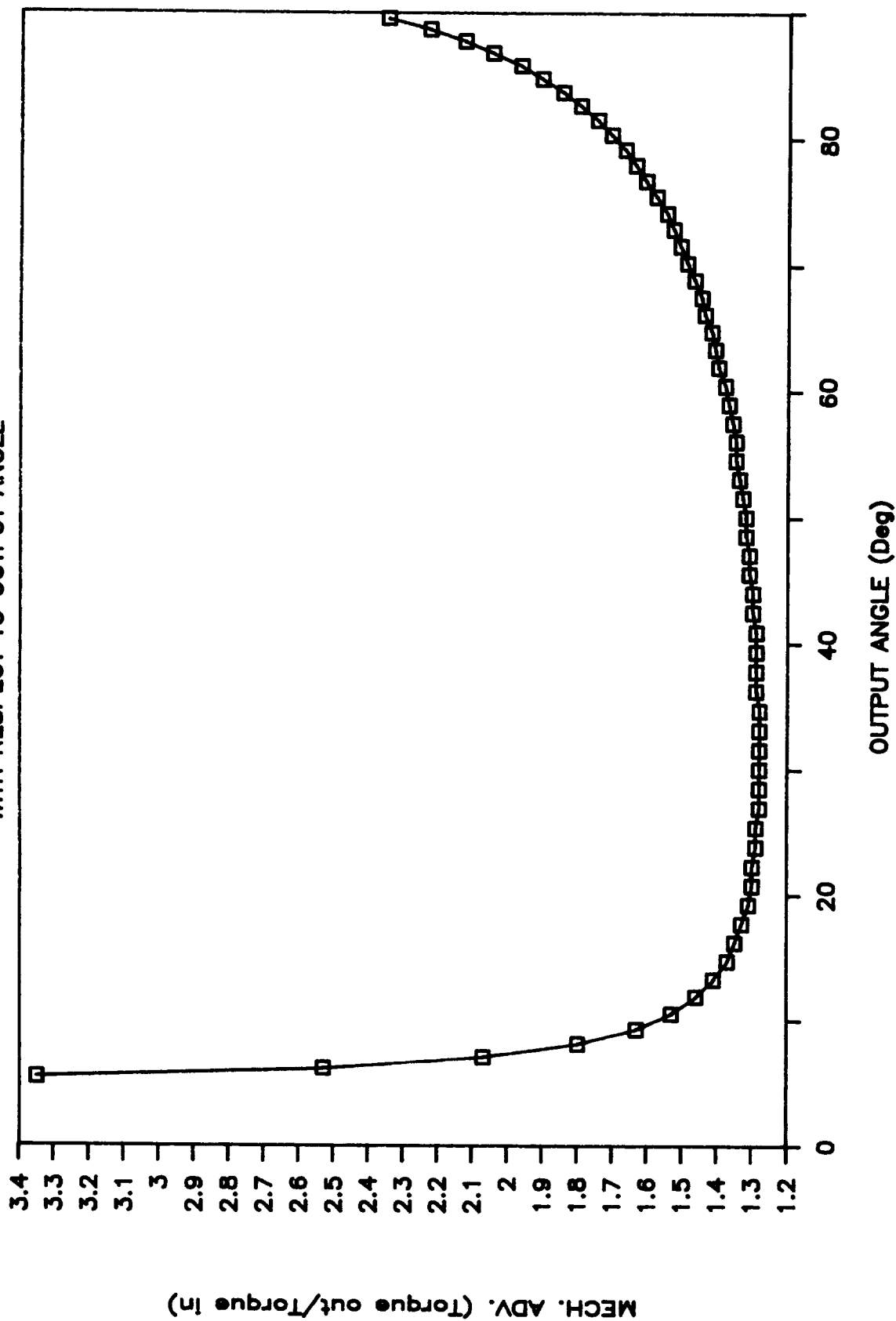
PROGRAM LNKDSN (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
RAB=1.5
RBC=3.42
RCD=2.1
RAD=4.0
THETIN=3.141593
PI=3.141593
R=0.0
PRINT*, ' INPUT ANG      OUTPUT ANG      MECHANICAL ADVANTAGE '
PRINT*, '      (DEG)      (DEG)      TORQUE OUT/TORQUE IN '
10 THETIN=THETIN+R
RBD=SQRT (RAB**2+RAD**2- (2*RAB*RAD*COS (THETIN)))
IF (SIN (THETIN) .LT..00001) THEN
PHI1=0.0
ELSE
PHI1=ASIN ((RAB*SIN (THETIN)) /RBD)
END IF
PHI2=ACOS ((RCD**2-RBC**2+RBD**2) / (2*RBD*RCD))
THETOT=PHI1+PHI2
GAMMA=ACOS ((RBC**2-RBD**2+RCD**2) / (2*RBC*RCD))
RAC=SQRT (RAD**2+RCD**2- (2*RAD*RCD*COS (THETOT)))
BETA=ACOS ((RBC**2-RAC**2+RAB**2) / (2*RAB*RBC))
ADVAN= (RCD*SIN (GAMMA)) / (RAB*SIN (PI-BETA))
IF (THETOT .LE. ((PI)/2.)) THEN
ANGL=180./PI
AIN=THETIN*ANGL
AOUT=THETOT*ANGL
WRITE (6,100) AIN,AOUT,ADVAN
100 FORMAT (2X,F7.3,6X,F5.2,8X,F4.2)
R=-.03490659
GOTO 10
ELSE
END IF
END

```

INPUT ANG (DEG)	OUTPUT ANG (DEG)	MECHANICAL ADVANTAGE TORQUE OUT/TORQUE IN
180.000	6.23	3.67
178.000	6.88	2.67
176.000	7.72	2.14
174.000	8.74	1.83
172.000	9.89	1.65
170.000	11.16	1.53
168.000	12.50	1.45
166.000	13.91	1.39
164.000	15.37	1.35
162.000	16.86	1.33
160.000	18.39	1.30
158.000	19.93	1.29
156.000	21.49	1.28
154.000	23.06	1.27
152.000	24.64	1.26
150.000	26.23	1.26
148.000	27.83	1.25
146.000	29.43	1.25
144.000	31.03	1.25
142.000	32.64	1.25
140.000	34.24	1.25
138.000	35.85	1.25
136.000	37.45	1.25
134.000	39.06	1.25
132.000	40.66	1.25
130.000	42.26	1.25
128.000	43.85	1.25
126.000	45.44	1.26
124.000	47.03	1.26
122.000	48.61	1.27
120.000	50.19	1.27
118.000	51.76	1.27
116.000	53.33	1.28
114.000	54.89	1.29
112.000	56.44	1.29
110.000	57.99	1.30
108.000	59.52	1.31
106.000	61.05	1.31
104.000	62.57	1.32
102.000	64.08	1.33
100.000	65.58	1.34
98.000	67.07	1.35
96.000	68.54	1.36
94.000	70.00	1.37
92.000	71.45	1.39
90.000	72.89	1.40
88.000	74.31	1.41
86.000	75.72	1.43
84.000	77.11	1.45
82.000	78.48	1.47
80.000	79.83	1.49
78.000	81.16	1.51
76.000	82.48	1.54
74.000	83.77	1.56
72.000	85.03	1.59
70.000	86.27	1.63
68.000	87.49	1.66
66.000	88.68	1.71
64.000	89.83	1.75

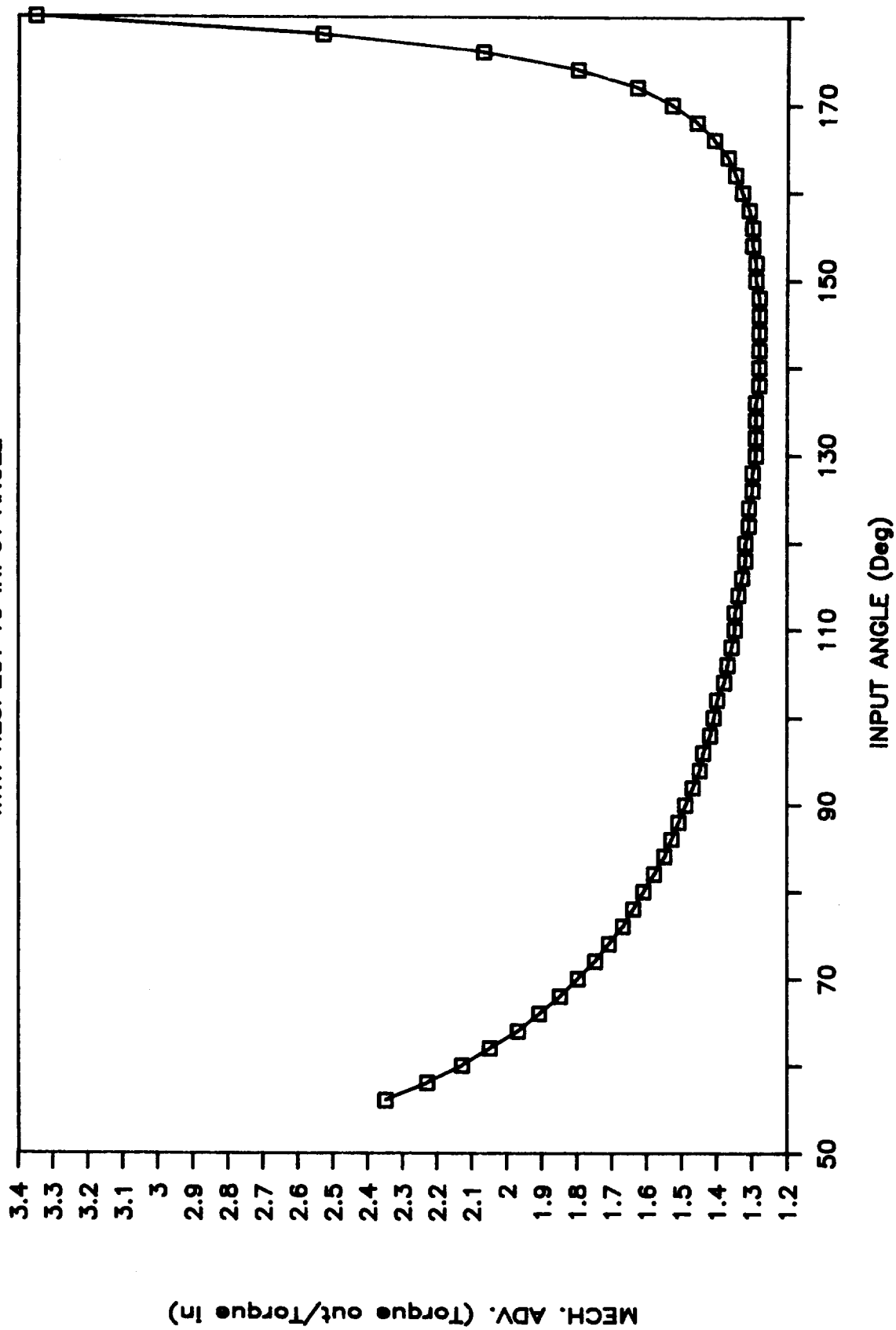
$\rightarrow T_{in} = 3.17 \text{ N} \cdot \text{m}, T_{out} = \frac{3.17}{1.53} = 2.07$

MECHANICAL ADVANTAGE OF FOUR BAR LINK. WITH RESPECT TO OUTPUT ANGLE



MECHANICAL ADVANTAGE OF FOUR BAR LINK.

WITH RESPECT TO INPUT ANGLE



Appendix

8.2

Cam Analysis Computer Program

```

PROGRAM TORQ (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT)
DIMENSION DIS (100), SL (100), TOR (100)
P=32.29
DO 10, IQ=1, 84
DIS (IQ) = (IQ-1) *.001476378
10 CONTINUE
DO 20 IQ=2, 83
SL (IQ) = (DIS (IQ+1) - DIS (IQ-1)) / 2.
20 CONTINUE
DO 30 IQ=2, 83
TOR (IQ) = P * (SL (IQ) + .15 * (.23622 + DIS (IQ))) * 2
30 CONTINUE
PRINT*, ' CAM ANGLE    DISPLACEMENT    SLOPE OF    TORQUE '
PRINT*, '   (DEG)        (INCH)        CAM SURF    (LB*IN) '
DO 40 IQ=2, 83
WRITE (6, 35) (IQ-1), (DIS (IQ) * 2), SL (IQ), TOR (IQ)
35 FORMAT (3X, I2, 10X, F5.4, 9X, F5.4, 6X, F6.3)
40 CONTINUE
END

```

CAM ANGLE (DEG)	DISPLACEMENT (INCH)	SLOPE OF CAM SURF	TORQUE (LB*IN)
1	.0030	.0015	2.398
2	.0059	.0015	2.412
3	.0089	.0015	2.427
4	.0118	.0015	2.441
5	.0148	.0015	2.455
6	.0177	.0015	2.469
7	.0207	.0015	2.484
8	.0236	.0015	2.498
9	.0266	.0015	2.512
10	.0295	.0015	2.527
11	.0325	.0015	2.541
12	.0354	.0015	2.555
13	.0384	.0015	2.570
14	.0413	.0015	2.584
15	.0443	.0015	2.598
16	.0472	.0015	2.612
17	.0502	.0015	2.627
18	.0531	.0015	2.641
19	.0561	.0015	2.655
20	.0591	.0015	2.670
21	.0620	.0015	2.684
22	.0650	.0015	2.698
23	.0679	.0015	2.713
24	.0709	.0015	2.727
25	.0738	.0015	2.741
26	.0768	.0015	2.755
27	.0797	.0015	2.770
28	.0827	.0015	2.784
29	.0856	.0015	2.798
30	.0886	.0015	2.813
31	.0915	.0015	2.827
32	.0945	.0015	2.841
33	.0974	.0015	2.856
34	.1004	.0015	2.870
35	.1033	.0015	2.884
36	.1063	.0015	2.898
37	.1093	.0015	2.913
38	.1122	.0015	2.927
39	.1152	.0015	2.941
40	.1181	.0015	2.956
41	.1211	.0015	2.970
42	.1240	.0015	2.984
43	.1270	.0015	2.999
44	.1299	.0015	3.013
45	.1329	.0015	3.027
46	.1358	.0015	3.041
47	.1388	.0015	3.056
48	.1417	.0015	3.070
49	.1447	.0015	3.084
50	.1476	.0015	3.099
51	.1506	.0015	3.113
52	.1535	.0015	3.127
53	.1565	.0015	3.142
54	.1594	.0015	3.156
55	.1624	.0015	3.170
56	.1654	.0015	3.185
57	.1683	.0015	3.199
58	.1713	.0015	3.213
59	.1742	.0015	3.227
60	.1772	.0015	3.242
61	.1801	.0015	3.256
62	.1831	.0015	3.270
63	.1860	.0015	3.285
64	.1890	.0015	3.299

65	.1919	.0015	3.313
66	.1949	.0015	3.328
67	.1978	.0015	3.342
68	.2008	.0015	3.356
69	.2037	.0015	3.370
70	.2067	.0015	3.385
71	.2096	.0015	3.399
72	.2126	.0015	3.413
73	.2156	.0015	3.428
74	.2185	.0015	3.442
75	.2215	.0015	3.456
76	.2244	.0015	3.471
77	.2274	.0015	3.485
78	.2303	.0015	3.499
79	.2333	.0015	3.513
80	.2362	.0015	3.528
81	.2392	.0015	3.542
82	.2421	.0015	3.556

Appendix

8.3

Rock Deflection Calculations

CALCULATIONS

ASSUME: GRANITE AS MATERIAL

* TENSILE STRENGTH = $\sigma_T = 12 \frac{\text{MN}}{\text{m}^2}$

* SHEAR STRENGTH = $\tau_{\text{max}} = 32 \frac{\text{MN}}{\text{m}^2}$

Force needed to break specimen in TENSION

F = Force needed to break rock

$A_0 = \text{INITIAL AREA OF ROCK} = \pi r^2$

$r = \text{RADIUS OF SPECIMEN} = 60/2 = 30 \text{ mm}$

$F = \sigma_T \cdot A_0$

$F = 12,000,000 \frac{\text{N}}{\text{m}^2} \cdot \pi (30 \text{ mm})^2 \cdot \frac{1 \text{ m}^2}{1,000,000 \text{ mm}^2}$

$F = 33,929 \text{ N}$

Force needed to break specimen in BENDING

F = Force needed to break rock

I = CENTRAL MOMENT OF INERTIA OF CROSS SECTION OF BEAM

$I = \frac{\pi r^4}{4}$

L = LENGTH FROM BOTTOM OF SPECIMEN TO APPLICATION OF FORCE

C = DISTANCE FROM NEUTRAL AXIS TO FARTHEST MOST FIBER

$\sigma_T = \frac{F L C}{I}$

$F = \frac{\sigma_T I}{L C} = \frac{12,000,000 \frac{\text{N}}{\text{m}^2} \cdot \pi (30 \text{ mm})^4}{(2)(30)(\frac{1}{200})^4} = 127 \text{ N}$

TORQUE NEEDED TO BREAK ROCK SPECIMEN

T = TORQUE

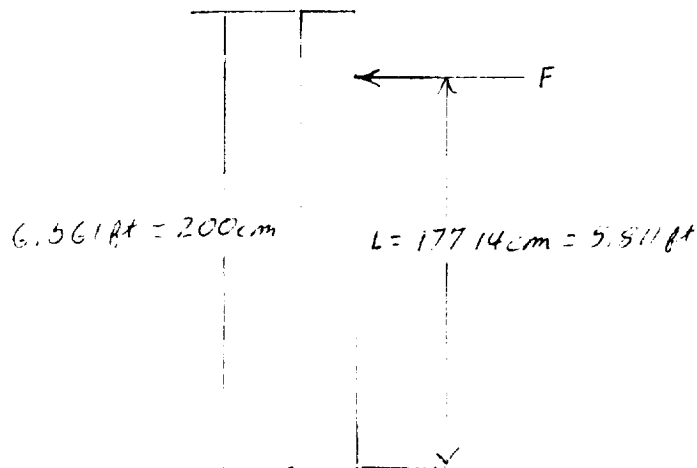
D = DIAMETER

$$\tau_{max} = \frac{16T}{\pi D^3}$$

$$T = \frac{\tau_{max} \pi D^3}{16} = \frac{32000000 \cdot \pi \cdot (60)^3}{16}$$

$$T = \underline{1357 \text{ Nm}}$$

Force Needed to Break A 60mm Diameter
Granite Specimen in Bending. The Specimen
is 2m in Length and the Force will be
Applied 91N (22.86cm) from the Top



TENSILE STRENGTH OF GRANITE $\sigma_T = 12,000,000 \frac{\text{N}}{\text{m}^2} = 1200 \frac{\text{N}}{\text{cm}^2}$

$$J_T = \frac{FLC}{E}$$

$$I = \frac{\pi r^4}{4} \text{ FOR CIRCULAR BEAM}$$

$$J_T = \frac{F(177.14)(3)}{63.617}$$

$$r = 3 \text{ cm}$$

$$I = 63.617 \text{ cm}^4$$

$$F = \frac{J_T(63.617)}{(177.14)(3)}$$

$$C = 3 \text{ cm} = \text{DISTANCE TO FURTHEST FIBER}$$

$$F = 143.65 \text{ N} = 143.65 \text{ N} \cdot \frac{224809 \text{ lb}_f}{1 \text{ N}} = 32.24 \text{ lb}_f$$

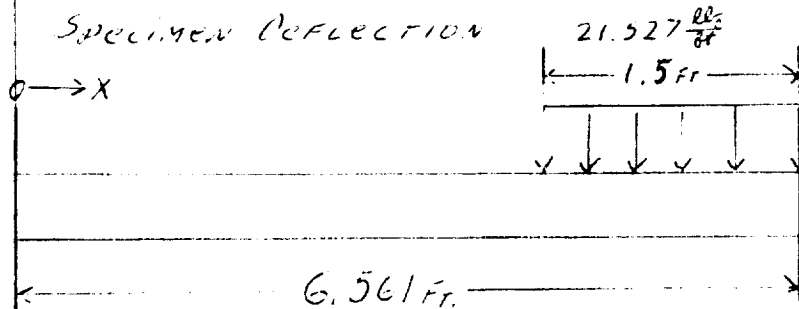
$$F = 32.24 \text{ lb}_f$$

Device is 1.5 ft Long

$$F = 21.53 \text{ lb}_f$$

CALCULATIONS

SPECIMEN DEFLECTION



DIFFERENTIAL EQUATION FOR BEAM DEFLECTION

$$M(x) = EI v''$$

$M(x)$ = MOMENT AS A FUNCTION OF x

E = MODULUS OF ELASTICITY = $45 \times 10^{10} \frac{N}{m^2}$

I = MOMENT OF INERTIA = $7.37 \times 10^{-9} m^4$

v'' = SECOND DERIVATIVE OF DEFLECTION

$$0 \leq x \leq 5.061 \text{ ft}$$

$$M(x) = 32.24(5.511 - x)$$

$$v'' = \frac{32.24}{EI} (5.511 - x)$$

$$(2) \quad v' = \frac{16.145}{EI} x - \frac{16.145}{EI} x^2 + C_1$$

$$(1) \quad v = \frac{43.52}{EI} x^2 - \frac{5.33}{EI} x^3 + C_1 x + C_2$$

BOUNDARY CONDITIONS

$$\text{At } x = 0, \quad v = 0, \quad C_2 = 0$$

$$\text{At } x = 0, \quad v' = 0, \quad C_1 = 0$$

$$v = \frac{43.52}{EI} x^2 - \frac{5.33}{EI} x^3$$

$$5.061 \leq x \leq 6.561$$

$$M(x) = 10.76 x^2 - 141.24 x + 463.33$$

$$v'' = \frac{10.76}{EI} x^2 - \frac{141.24}{EI} x + \frac{463.33}{EI}$$

$$v' = \frac{3.59}{EI} x^3 - \frac{70.62}{EI} x^2 + \frac{463.33}{EI} x + C_3$$

$$v = \frac{.847}{EI} x^4 - \frac{23.54}{EI} x^3 + \frac{231.67}{EI} x^2 + C_3 x + C_4$$

$$\text{At } x = 5.061 \text{ ft}$$

$$V = \frac{93.82}{EI} x^2 - \frac{535}{EI} x = \frac{.847}{EI} x^4 - \frac{23.54}{EI} x^3 + \frac{231.67}{EI} x^2 + C_3 x + C_4$$

$$V' = \frac{187.64}{EI} x - \frac{10.745}{EI} x^2 = \frac{3.99}{EI} x^3 - \frac{70.62}{EI} x^2 + \frac{463.33}{EI} x + C_3$$

$$\therefore C_3 = -.0067$$

$$C_4 = .0085$$

$$\text{at } x = 6.561 \text{ ft}$$

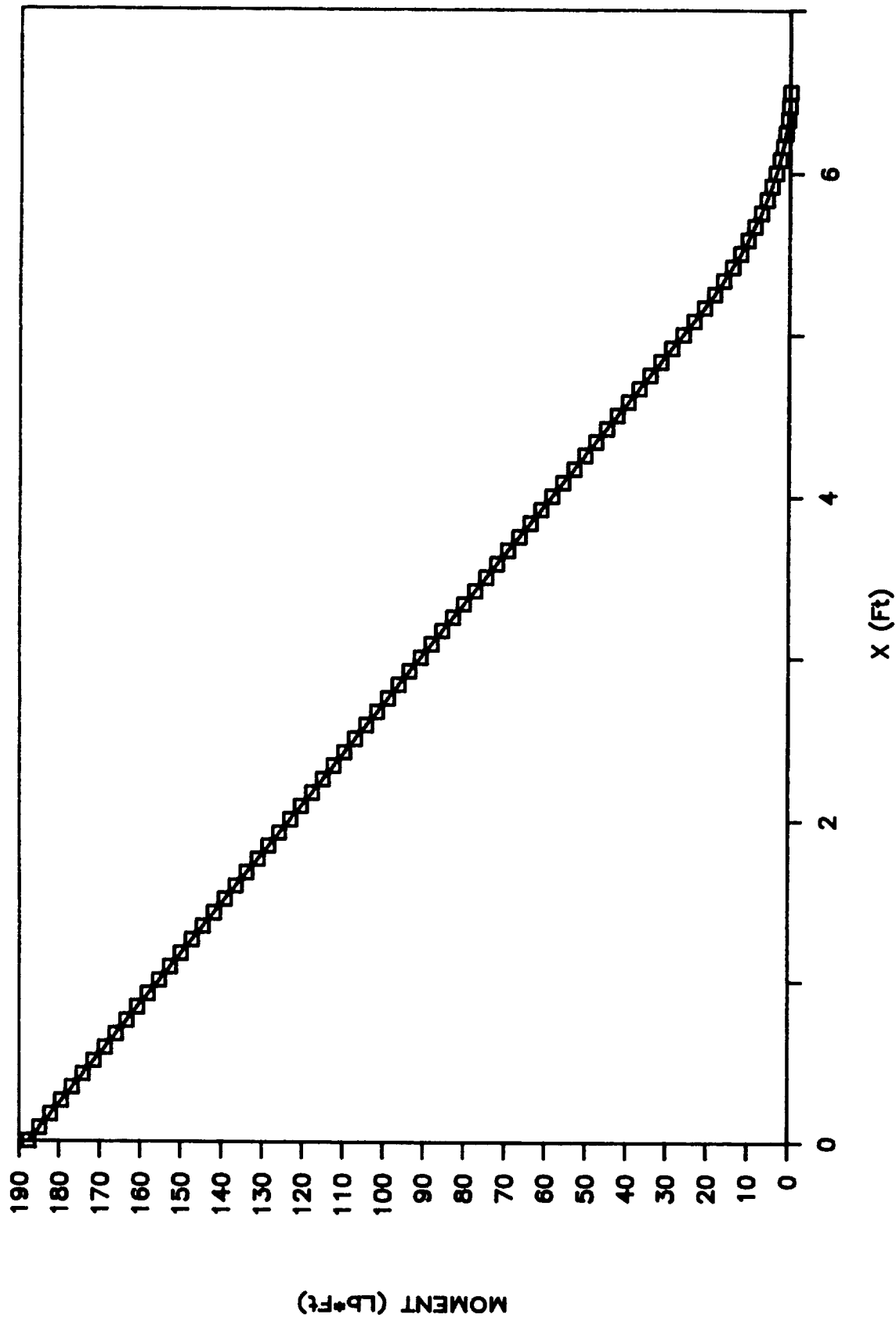
$$V = \frac{.847(6.561)^4}{EI} - \frac{23.54(6.561)^3}{EI} + \frac{231.67(6.561)^2}{EI} + (-.0067)(6.561) + .0085$$

$$V = .036426 \text{ ft} = .437 \text{ in}$$

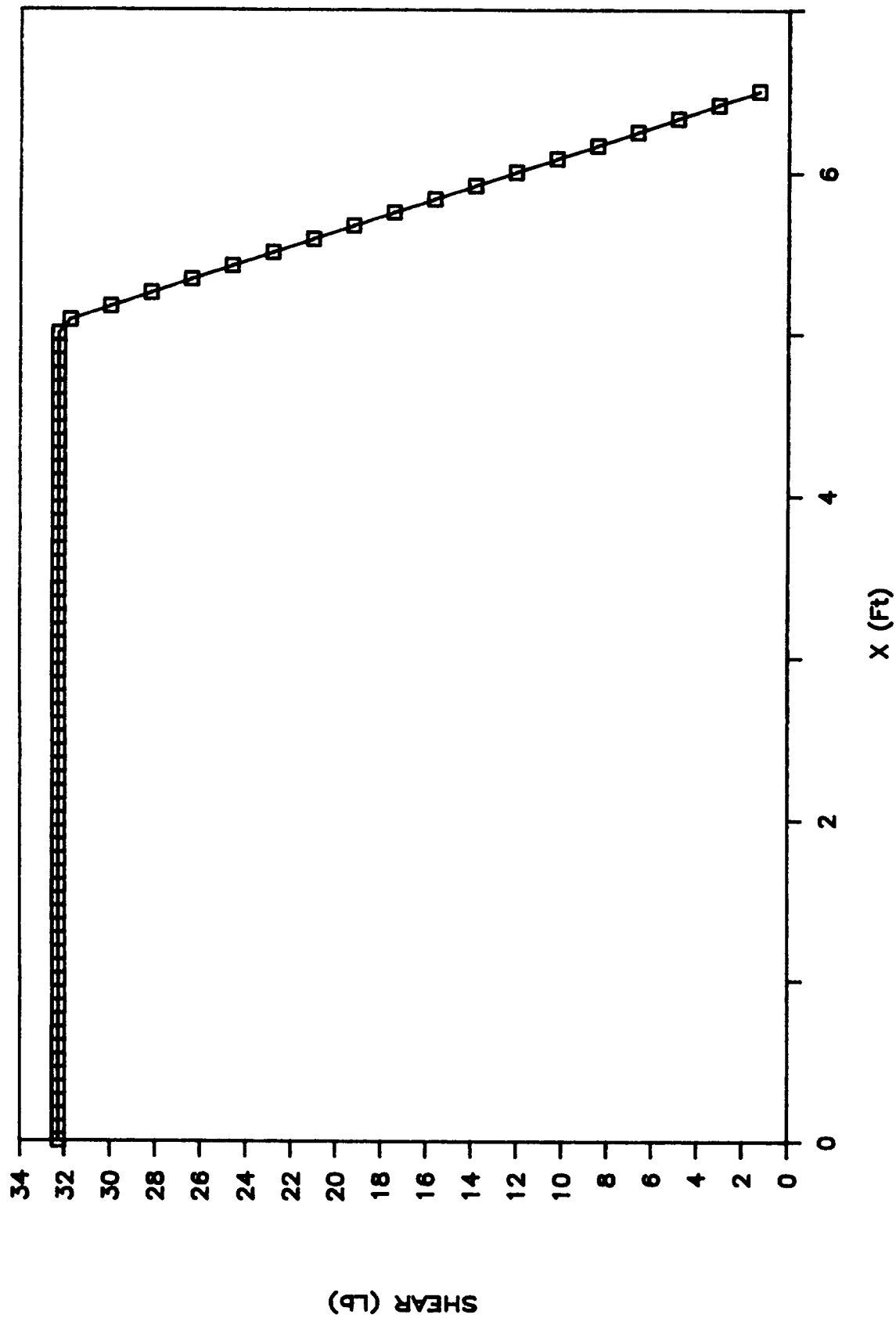
$$\text{at } x = 5.061 \text{ ft}$$

$$V = .0240 \text{ ft} = .29 \text{ in}$$

MOMENT DIAGRAM FOR ROCK SAMPLE



SHEAR DIAGRAM FOR ROCK SAMPLE

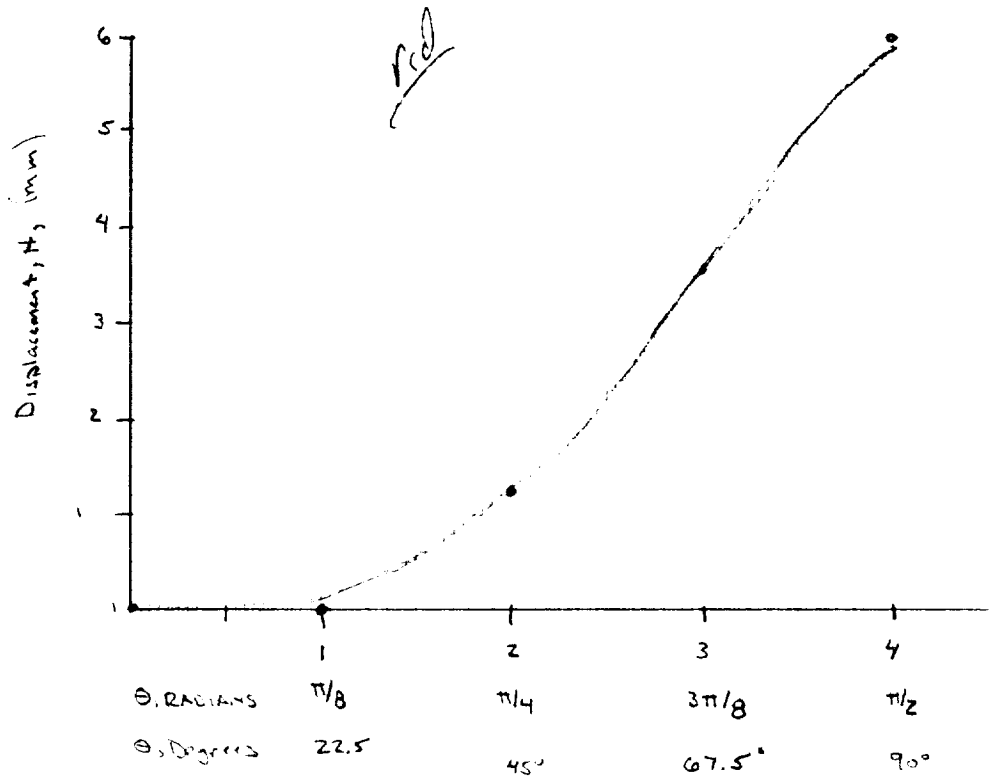
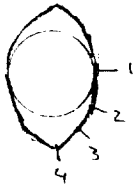


Appendix

8.4

Cam Analysis Calculations

Actual Size of CAM



$$N = \text{RPM} = \frac{\text{Rev}}{\text{min}} = \frac{1/4 \text{ Rev}}{1.6 \text{ sec}} \times \frac{60 \text{ sec}}{1 \text{ min}} = 15 \text{ RPM}$$

Elliptical Shape Cam

Max Displacement = 6 mm

Appendix

8.5

Weekly Progress Reports

**SCHOOL OF MECHANICAL ENGINEERING
GEORGIA INSTITUTE OF TECHNOLOGY**

WINTER QUARTER 1989

ME 4182 MECHANICAL DESIGN ENGINEERING

Progress Report: 1/11/89

Professor: Mr. J. W. Brazell

Group 3: Core Sample Extractor

Jim Akins(Group Leader)
Billy Cobb
Mark Pernik
James Milhollin
Jeff Leaptrot
Steve Hart

The group met in the Library on Sunday, January 8, at 7:00 pm. The object of this meeting was to begin discussing ideas about the project but it soon became obvious that we did not have enough information to proceed. We then used the time to assemble questions about the project details to ask Mr. Brazell in the Wednesday meeting. Some of the questions we came up with were:

1. What are the composition/characteristics of the sample material?
2. What should be the size of the sample?
3. Are there any restrictions in the movement of the skitter?
4. Are there any space restrictions for the extractor on the skitter?
5. Are we responsible for the design of the containers?

SCHOOL OF MECHANICAL ENGINEERING
WINTER QUARTER, 1989

ME 4182
MR. J.W. BRAZELL

PROGRESS REPORT, WEEK #2
JANUARY 18, 1989
CORE SAMPLE EXTRACTOR GROUP

GROUP MEMBERS

James Akins(group leader)
Steve Hart
Mark Pernik
Jeff Leaptrotte
Billy Cobb
James Milhollin

Thursday January 12, 1989- 7:00-8:30 p.m.

-group met to continue brainstorming for conceptual project ideas. A reverse 45 degree angle core extractor. (see print #1) and the "snake grasper" (see print #2) resulted from our discussion. Both of these ideas address the constraints of precise sample location and the control and removal of samples with varying composition.

- the group also attached the core sample packaging and storage idea but further research is needed in order to decide what applications are needed.

Tuesday January 17, 1989- 7:00-11:00 p.m.

- group met to identify all known constraints for the problem statement.

- the containment of the core sample was discussed in more detail. Several thoughts were generated.

Wednesday January 18, 1989- 6:00-7:00 p.m.

- met with Mr. Brazell and discussed the project and more recommendations were made.

- turned in problem statement

SCHOOL OF MECHANICAL ENGINEERING
WINTER QUARTER, 1989

ME 4182

**CORE SAMPLE EXTRACTOR GROUP
WEEKLY REPORT #3**

January 25, 1989

GROUP MEMBERS

James Akins(Group Leader)
Steve Hart
Mark Pernik
Jeff Leaptrotte
Billy Cobb
James Milhollin

Thursday, January 19, 1989: 7:00-9:00 p.m.

- group members assembled on the second floor east side of the library in the micro-film department.
- after finding out that we were doing the wrong project, we looked up information on Acker Drilling equipment to get some basic conceptual ideas on how to extract the core out of the two meter incremented hole.

Monday, January 23, 1989: 7:00 - 8:30 p.m.

Tuesday, January 24, 1989: 7:00- 9:00 p.m.

****Decided on project design****

- group met to continue brainstorming on ideas.
- some of the ideas included sending down a "sleeve-chuck assembly" to bring the core out hopefully one piece. The chuck like contraption is connected to the bottom of the sleeve. There will be two cables running down both sides of the sleeve and each end is connected to each side of the chuck. The chuck is spring loaded so that when a force is exerted upward on the cables, the chuck will compress inwards. As of this date the cables are put into tension by some type of wenching device which will bring the contraption and the core sample upward out of the hole.
- the container application is also being addressed heavily. Ideas of a revolving tray with 25 sample containers is of interest. Also a hinged box in which the core samples are laid horizontal and stacked in tiers.

RESULTS FROM THE BRAINSTORMING SESSION CONDUCTED ON JANUARY 29, 1989

The design was broken down into what we felt were the five basic components: get something into and out of the hole, breaking, holding, and storing the sample. Some of the ideas which were generated can perform more than one of these functions and are listed in both categories.

GET SOMETHING INTO AND OUT OF THE HOLE

- drop it (free fall)
- use a wench (controlled fall)
- a rod extends into the hole (possible the same tooling being currently designed)
- crawl on the walls with wheels straight down or in a helix pattern
- forced drop with a spring or an explosive charge
- screw it down
- extend rails into the whole and then drop it
- extend it with a pill cup effect
- crawl on walls like a slinky/caterpillar

BREAK SAMPLE OFF

- | | |
|----------------------------------|--------------------|
| - vibrations | - laser |
| - cut it | - explosive charge |
| - bending (use a wedge, cams) | - tension |
| - acid/chemicals | - shear |
| - pincers at bottom and tension | - plasma torch |
| - jack hammer effect at bottom | - shatter |
| - water or air at high pressures | - fatigue |

WAYS TO HOLD THE SAMPLE

- adhesive (hook and sleeve)
- screw onto sample
- basket retainer
- suction cups
- pincers

HOLD cont.

- chuck
- make a notch and insert something
- magnetize the rock
- half sleeve (two parts)
- Chinese finger
- helix or spring

STORING THE SAMPLE

- indexing systems (circular horizontal)
- drop sample onto a ramp and divert its path
- hinged case
- spring loaded tube release
- release pincers
- magnetized dual sleeve

SCHOOL OF MECHANICAL ENGINEERING
WINTER QUARTER, 1989

ME 4182

**CORE SAMPLE EXTRACTOR GROUP
WEEKLY REPORT #4**

February 1, 1989

GROUP MEMBERS

James Akins(Group Leader)
Steve Hart
Mark Pernik
Jeff Leaptrotte
Billy Cobb
James Milhollin

Sunday, January 29, 1989: 2:00-4:00 p.m.

- group met to continue brainstorming.
- what we did was identify many creative ideas to get the core extractor down in the hole, then pulling the extractor out of the hole with a good sample, and finally delivering the sample to a container in which the sample will be stored.
- *a list of these ideas are connected to the back of this progress report.*

Monday, January 30, 1989: 3:00-4:30 p.m.

- group met to discuss what each individual member of the group has found concerning different areas of the project.
- Mark and James Milhollin met to look up several patents dealing with the extraction process.
- Jim Akins and Steve Hart are in the process of using Mr. Brazell's abstract book as well as other government documents in the library to see what is already being used and what interesting ideas the group could develop from their findings.
- Billy Cobb is looking up different strength characteristics for certain types of rock that are typical below the moons surface.
- Jeff Leaptrotte is working with Jill Harvey to get some general information on the project. In the process of making several CAD drawings of certain ideas the group is coming up with.

SCHOOL OF MECHANICAL ENGINEERING
WINTER QUARTER, 1989

ME 4182

CORE SAMPLE EXTRACTOR
GROUP #3
WEEKLY PROGRESS REPORT
February 8, 1989

Group Members

James Akins(Group Leader)
Steve Hart
Mark Pernik
Jeff Leaptrotte
Billy Cobb
James Milhollin

Thursday February 2, 1989: 3:00- 4:00 p.m.

- group met to discuss more ideas on the extraction of the core sample. We started addressing the idea of what happens if the core breaks and falls sideways on the edge of the hole.
- Researched some of the technical reports from Mr. Brazell's abstract book. The ideas were vague but a little helpful.

Friday, February 3, 1989: 12:00- 1:00 p.m.

- group met to discuss more on bending, torsion, and tension of extracting the sample.

Monday, February 6, 1989: 5:30-6:30 p.m.

- group met to continue discussing ideas and started outlining the upcoming oral presentation for Wednesday.

Tuesday, February 7, 1989: 2:00-4:00 p.m.

- group met to go over what will be presented in the speech on Wednesday. We will present three ideas which deal with torsion, tension, and bending of the core sample to break it.

Tuesday, February 7, 1989: 8:00-9:30 p.m.

- group met to practice and refine the speech. Steve Hart will be giving the oral presentation.

**SCHOOL OF MECHANICAL ENGINEERING
WINTER QUARTER, 1989**

ME 4182

Mr. J.W. Brazell

**WEEKLY PROGRESS REPORT
GROUP #3
CORE SAMPLE EXTRACTOR GROUP**

February 15, 1989

GROUP MEMBERS

James Akins(Group Leader)

Steve Hart

Mark Pernik

Jeff Leaptrotte

Billy Cobb

James Milhollin

Thursday, February 9, 1989: 3:00-4:30 p.m.

Friday, February 10, 1989: 3:00 - 4:00 p.m.

- group met to discuss more about the project.

THE WEEKS HIGHLIGHTS

Monday, February 13, 1989: 6:00- 9:00 p.m.

- group met to research the different properties of the core sample that would be extracted. After looking diligently at microfiche on the second floor of the library we concluded that the rock sample is primarily composed of basalt, titanium oxide and only about 10 to 20% of the rock is composed of Ilmenite.

- later we took the granite sample and tried to break it. We attempted this by using two stainless steel rods and shaping them in the form of a helical spring which was placed over the sample. Then with the use of a welder we applied 40 to 75 amps of current to these rods but no reaction took place.

Tuesday, February 14, 1989: 3:00-4:30 p.m.

- Steve Hart met with some of the men in the materials lab and found some very interesting information. First, if we use a bellow at the bottom where we are breaking our sample and use hydraulics to

supply the fluid needed to break the sample , it will take alot less enery to accomplish this than our electrical experimentation. The concept will be explained in greater detail at the meeting. We are in the process of contacting a bellow manufacturer to find out more on the necessary requirements and if it can fit in with what our design requires. We are also looking at the stainless steel tubing that will be used to transport the fluid down to the bellow.

SCHOOL OF MECHANICAL ENGINEERING
WINTER QUARTER, 1989

ME 4182
MR. J.W. BRAZELL

PROGRESS REPORT, WEEK
FEBRUARY 22, 1989
CORE SAMPLE EXTRACTOR GROUP
Group #3

GROUP MEMBERS

James Akins(group leader)
Steve Hart
Mark Pernik
Jeff Leaptrotte
Billy Cobb
James Milhollin

Thursday February 16, 1989: 4:30 - 5:30 p.m.

- group met to discuss more on the "cam design" core extractor.
- James Milhollin drew up a picture of the cam design and presented it to the group. After thoroughly discussing this design, we feel like this design is best suited for our needs. We are in the process of putting calculations together to determine what criteria the cam design will have to meet.
- group also discussed sample container applications more. We need to talk to the dump train group to find out how big the "dumper" is, and the shape, so our design will coincide with their design for better efficiency.

Monday, February 20, 1989: 8:00 - 9:30 p.m.

- group met to continue discussing the cam design.
- After this weeks meeting with Professor Brazell, we will probably have a better idea of how to construct our storage container and what materials it should be made of.

Tuesday, February 21, 1989: 3:15 - 4:30 p.m.

- group members gathered to go over the cam design again.
- Certain group members will be looking up information on containers and others will be working more on the cam design.
- Hopefully the rod-changer group will provide our group with information on what will happen after the sample is taken out of the hole and ready to be put into storage.

**SCHOOL OF MECHANICAL ENGINEERING
WINTER QUARTER, 1989**

ME 4182

**CORE SAMPLE EXTRACTOR GROUP
GROUP #3
WEEKLY PROGRESS REPORT
FEBRUARY 29, 1989**

GROUP MEMBERS

James Akins
Steve Hart
Mark Pernik
James Milhollin
Billy Cobb
Jeff Leaptrotte

Thursday, February 23, 1989: 4:30-5:30 p.m.

- group met to continue discussing the design of the cam actuated extractor to break core sample. Figuring what lengths are needed and what restrictions are there. A lot of analysis is being done on this part of the project.

Sunday, February 26, 1989: 7:00-9:00 p.m.

- group met to discuss cam design more and also discuss the container more but still more emphasize put on core extractor.

Monday, February 27, 1989: 3:00-5:00 p.m.

- group met to begin working on the rough draft to be turned in on Wednesday. Everything is in tact but we are still lacking sufficient information to obtain a really good container design. A lot of analysis is being done at this point in time.

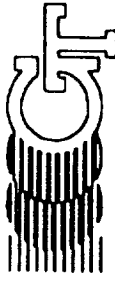
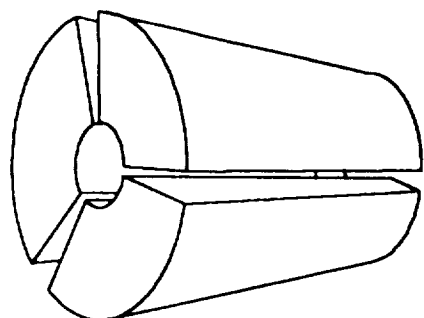
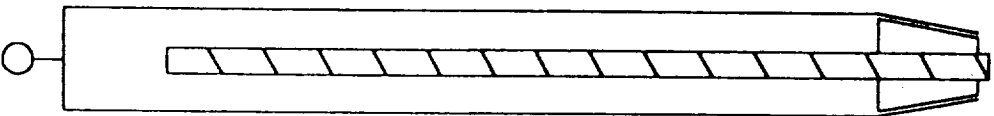
Tuesday, February 28, 1989: 3-5 p.m ; 6-12 p.m.

-group met to put finishing touches on the rough draft report. Container design is being discussed thoroughly while the Cam design process is being completed.

Appendix

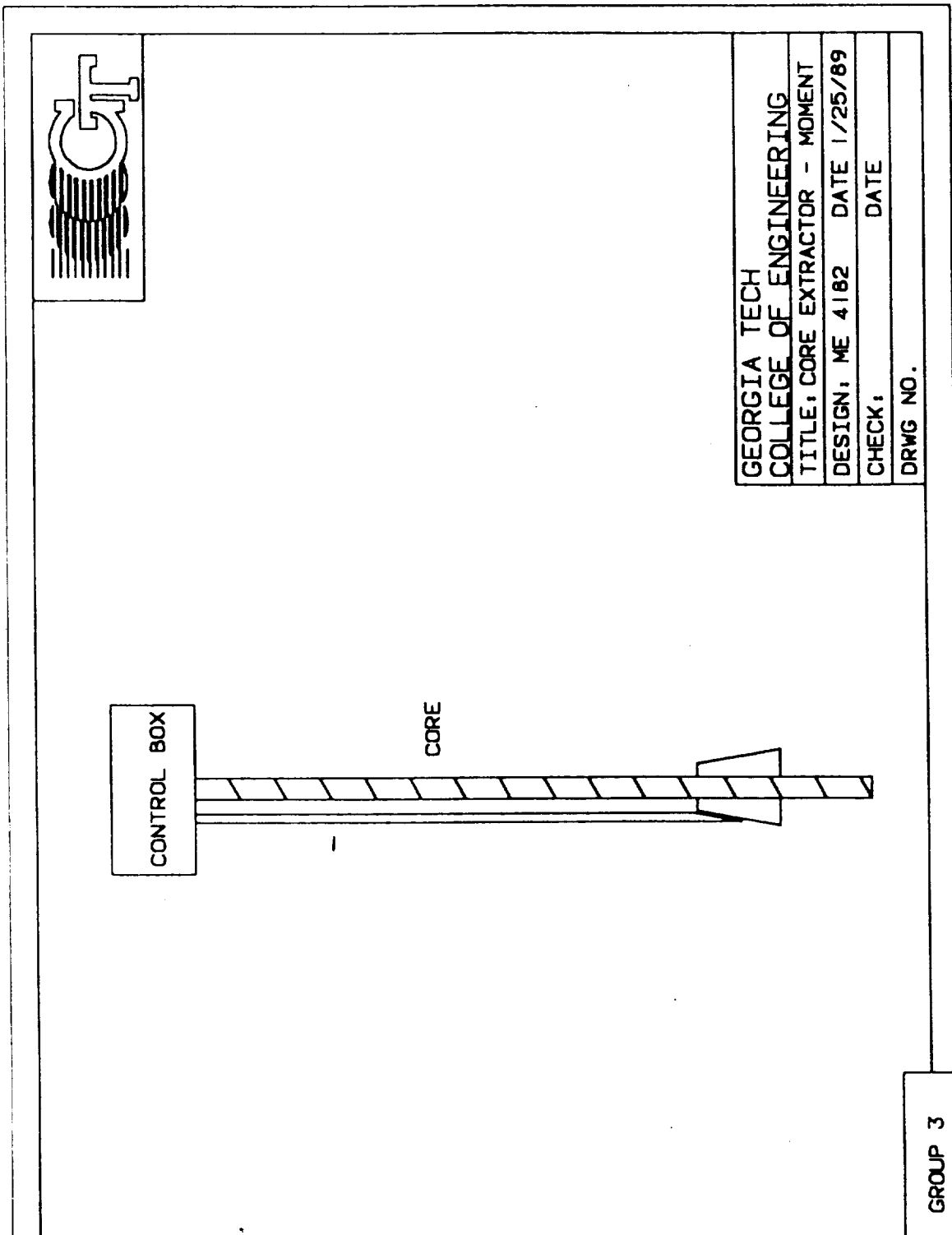
8.6

Preliminary Designs and Description

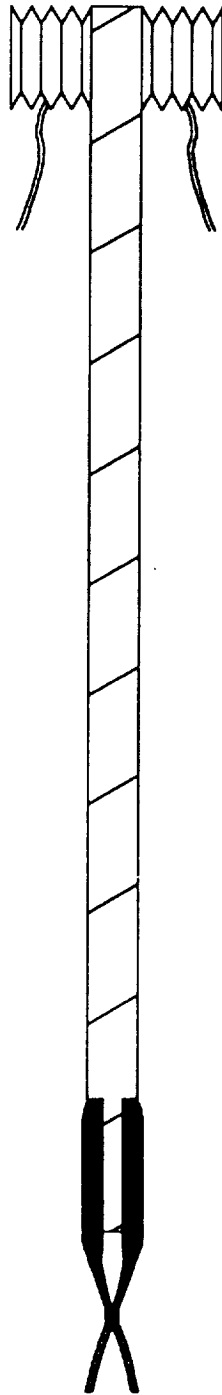
	 <p style="text-align: center;">CHUCK</p>	GEORGIA TECH COLLEGE OF ENGINEERING	
		TITLE: CORE EXTRACTOR	
		DESIGN: ME 4182	DATE 1/25/89
		CHECK:	DATE
		DRWG NO.	
		GROUP 3	

The first idea adopted about grasping the sample was the 'Drill Chuck' mechanism. The basic principle was similar to that used in a drill. When one twists the outside casing, the chuck moves inward. It was initially thought that the chuck idea would be used in twisting, bending or pulling the sample apart.

The main problem with the chuck was the possibility that it might not grasp the sample well enough to twist or pull the sample apart. The forces needed in either one of these operations was much greater than bending. This was one of the initial conceptual designs for breaking by bending.



This is one of the conceptual designs of the drill chuck being used for bending the sample. A wedge is being used between the chuck and outside wall for breakage. This idea was later perfected.


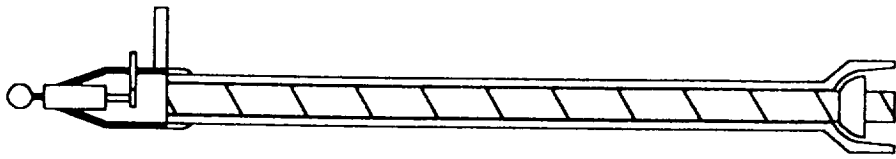


GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE: SHEAR CORE EXTRACTOR
DESIGN: ME 4182 DATE 2/15/89
CHECK: DATE
DRWG NO.

GROUP 3

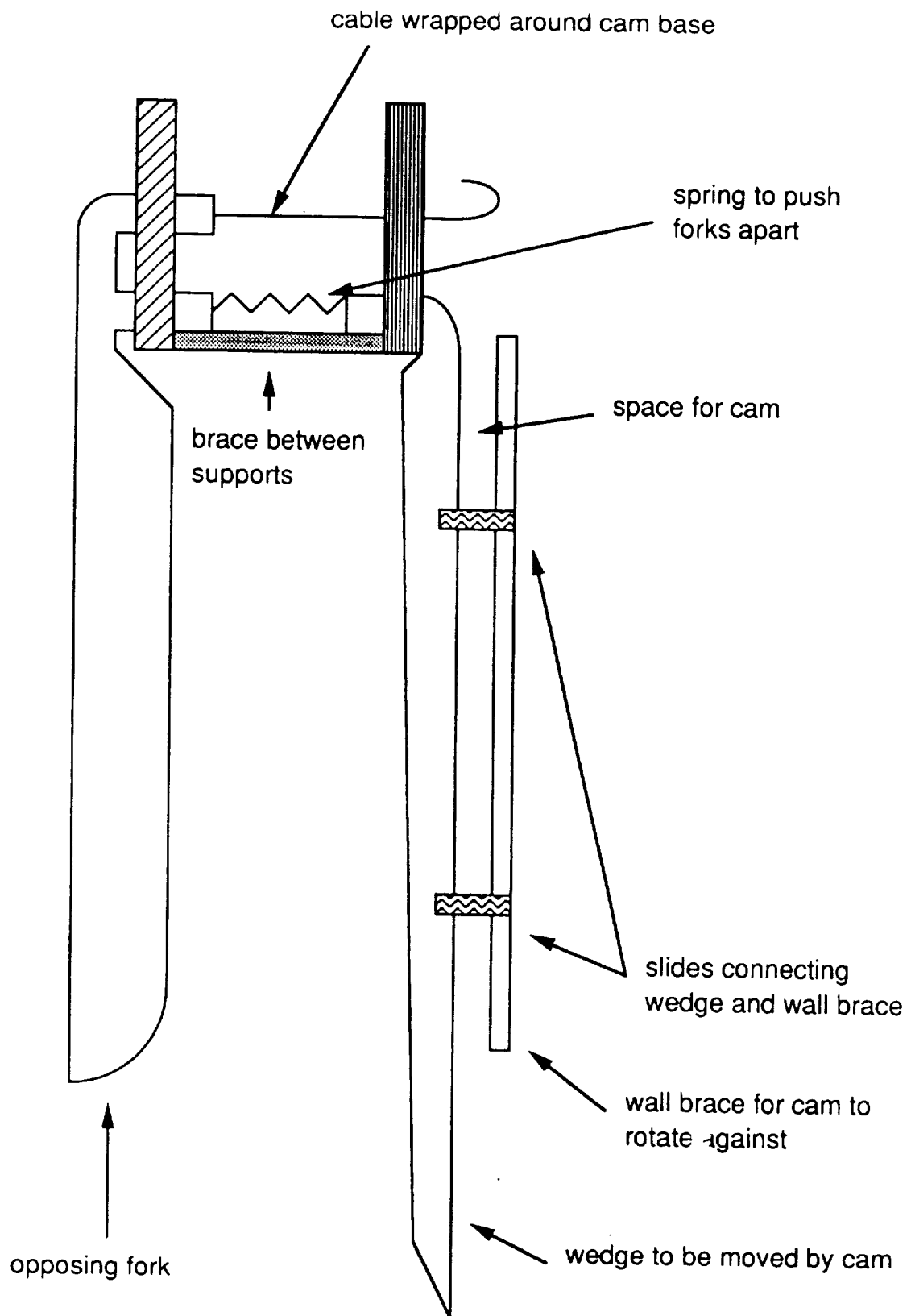
A strong candidate at one time was the Shear Core Extractor using hydraulic bellows. A hydraulic fluid would rush to the bottom, creating enough force to shear the sample. The shovel, shown at the top, would then be lowered to grasp the sample. This 'Pole-Hole Digger' type of tool was later implemented into our current design

The major problem was a) finding bellows strong and durable enough to sustain the shear force and b) obtaining adequate sealing for the hydraulic fluid. Had both these problems been alleviated, the Shear Core Extractor would have been a viable candidate.

			GEORGIA TECH
			COLLEGE OF ENGINEERING
			TITLE: CORE EXTRACTOR
			DESIGN: ME 4182 DATE 2/1/89
			CHECK: DATE
DRWG NO.			
GROUP 3			

The bending concept was then re-examined using a cam-gear system at the top of the core. This system would be such that it would exert a large force in order to break the sample. A tube sleeve would fit over the sample in order to retain the sample upon breakage.

Some problems were evident with this design. First, there had to be a small tolerance for the tube to fit over the core sample. Secondly, the problem of dust and debris getting into the gears was evident. Without lubrication and the high wear problem, the life of the system would be small.



In order to improve upon the previous design, the sleeve was replaced by the 'Pole-Hole Digger' concept. This eliminated the need of the tube sample and maximized the use of the 'Digger'. The gears were replaced by a spring system a large cam was used along the side of the hole. The would constitute a more evenly distributed force along the side of the core sample and thus a smaller breakage force.

This system was later optimized further into our current proposal by replacing the spring system with a linkage system.

